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ABSTRACT

This guide is intended to provide stimuli for discussion and review of ecological principles and their relevance to daily human existence. The illustrations, purposefully detailed and complex, are intended to provide a basis for in-depth discussion. The bulletin is intended to supplement classroom materials and also to serve non-classroom situations involving environmental education such as Scouting and Youth Conservation Corps. The book is a summary of ecological concepts presented as a game in which organisms interact with each other and their non-living environment. (Author/RE)

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UNDERSTANDING THE GAME OF THE ENVIRONMENT

U.S. DEPARTMENT OF HEALTH,
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AN ILLUSTRATED GUIDE TO UNDERSTANDING ECOLOGICAL PRINCIPLES

by
David R. Houston
Northeastern Forest Experiment Station

SE 030 496

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UNITED STATES DEPARTMENT OF AGRICULTURE
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WASHINGTON, D.C.

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THE AUTHOR

This bulletin was written and designed by DAVID R. HOUSTON, a Research Plant Pathologist with the Forest Service, U.S. Department of Agriculture, Northeastern Forest Experiment Station, Hamden, Conn. The materials presented here were developed by Dr. Houston as part of a cooperative program in which he established and taught an introductory course in ecology in 1973 and 1974 at Daniel Hand High School, Madison, Conn.

ACKNOWLEDGMENT
David M. Carroll, Warner, N.H., provided the illustrations for this bulletin. Mr. Carroll, who has illustrated several Forest Service publications, is an ardent herpetologist.

5

FOREWORD

Ecological concepts are not new; the term "ecology" was coined in 1869. Derived from the Greek "oikos," or home, ecology literally means the study of organisms in their homes. Today we usually define ecology as the study of the relationships between organisms and their environment—or environmental biology.

Today's energy crisis, food shortages, and population explosion clearly indicate that basic ecological principles, once viewed as interesting but somewhat irrelevant phenomena restricted to lesser organisms and their environment, are entirely applicable to human life as well.

The relationship of people to their environment is of ever greater importance as the demands of a burgeoning population and the ability to manipulate the environment increase at geometric rates.

As a supplement to other classroom materials and field experiences, *Understanding the Game of the Environment* should provide stimuli for discussion and review of ecological principles and their relevance to our daily existence. The illustrations, purposefully detailed and complex, are intended to provide a basis for in-depth discussion. We believe this bulletin also should be of value to special interest and youth organizations—members of the Youth Conservation Corps, Scouts, and others interested in understanding their environment.

Understanding the Game of the Environment is a summary of major ecological principles and concepts viewed as a game in which living organisms interact with each other and their nonliving environment. The use of game terminology helps place a bewildering array of facts and relationships into an understandable framework. All students are familiar with games, and they recognize the necessity of defining the Playing Field, identifying the Players, and understanding the Rules of the Game. Similarly, students understand that when Rules are violated and Fouls are committed, the Players will be Penalized.

Understanding the Game of the Environment includes the:
☐ *Playing Field* or *Environmental Arena* (Ecosystem).
☐ *Players* (The components of the ecosystem).
☐ *Rules of the Game* (Ecological principles including concepts of energy flow and material cycling).
☐ *Changing Players and Playing Fields* (Ecological succession or biotic change).
☐ *Fouls and Penalties* (Stresses on the ecosystem and their effects).
☐ *Methods of Improving the Game* (Playing within the rules).

CONTENTS

Page

I. THE PLAYING FIELD: THE ENVIRONMENTAL ARENA 1

II. THE PLAYERS 11
- The Producers 13
- The Consumers 21
- The Saprotrophs: Decomposer Consumers 29
- Organic Compounds 33
- Inorganic Substances 35
- Environmental Climate 37

III. RULES OF THE GAME 38
- Energy Flow Rules of the Game 39
  - First energy rule 39
  - Photosynthesis and respiration 40
  - One-way flow of energy 44
  - Second energy rule 44
  - Trophic level energy relationship 51
  - Ecological pyramids 51
- Material Cycling Rules of the Game 53
  - Cycle pools 53
  - Types of cycles 53
- Some Important Biogeochemical Cycles 57
  - The water cycle 57
  - The carbon cycle 58
  - The nitrogen cycle 60
  - The phosphorus cycle 66
  - The calcium cycle 75
  - The sulfur cycle 78

IV. CHANGING PLAYERS AND PLAYING FIELDS: ECOLOGICAL SUCCESSION 80
- Some Examples of Succession 82
  - Northern pond 82
  - Old field 84
  - Lake Michigan sand dune 86
  - Bare rock 88
  - Grassland 89
- Factors Affecting Succession 91
- Succession Versus Productivity 92
- People and Succession 92

- **V. FOULS AND PENALTIES** 94
  - **Some of Nature's Fouls** 97
    - Wildfire 97
    - Drought 98
    - Volcanism 99
    - Hurricanes 100
    - Overgrazing (insect defoliation) 101
  - **Some People Fouls** 105
    - Manipulation of ecosystems 109
      - Disruption of flood plains 109
      - Dredging and dumping 109
      - Growing monocultures 111
      - Strip mining 112
      - Excessive predator control 112
    - Depletion of finite resources 117
      - Agricultural land, forests, open space 117
      - Minerals and metals 119
      - Energy reserves 119
    - Pollution 124
      - Some cycles run amuck 127
        - Phosphorus 127
        - Nitrogen 129
        - Sulfur dioxide 131
        - Heavy metals 131
        - Hydrocarbons (chlorinated) 132
        - Hydrocarbons (oil) 135
        - Radioactive materials 137
        - Solid waste 139
        - Sewage 139
      - Messing up the flow of energy 141
        - Heat 141
- **VI. IMPROVING THE GAME** 146
  - **Abiding by the Rules** 147
    - Energy 147
    - Material cycling 151
  - **Careful manipulation of Ecosystems** 152
- **GLOSSARY OF ENVIRONMENTAL TERMS** 157

I. THE PLAYING FIELD:
THE ENVIRONMENTAL ARENA

Figure 1. — *The world, a hemisphere, a biome, a geographical region, a State, a township — all are ecosystems or environmental Arenas. But a forest, a pond, an estuary, or a shoreline is about as large an ecosystem as we can attempt to understand fully.*

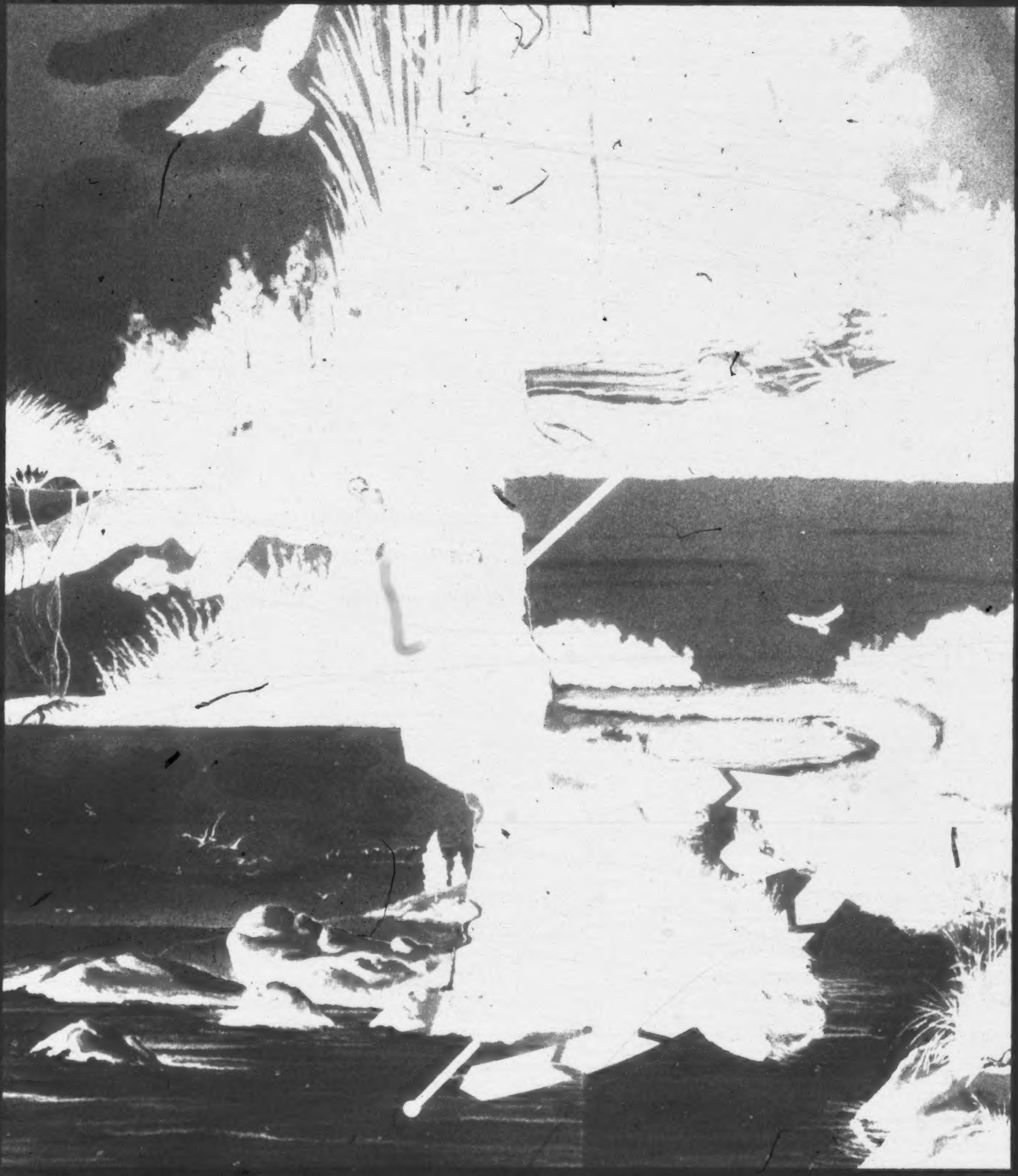
The Playing Fields or Arenas where the *Game of the Environment* is played are the geographic units where living plants and animals interact with each other and their environment according to ecological principles that govern the *flow of energy* and the *cycling of essential and nonessential materials.* Ecologists call these Arenas *ecosystems.*

As a matter of fact, the entire world can be considered an *ecological system* or ecosystem. But the world, and especially the thin mantle of soil, air, and water where all life exists—the *biosphere*—is difficult to study as a single unit because of its unwieldy size.

The continent of North America includes major regions, or *biomes,* that differ from each other in climate and in physiography. Biomes such as deserts, tundras, prairies, the coniferous forests of the West, and the deciduous forests of the East also differ markedly from each other in major life forms of their plants and animals. Each of these biomes can be considered an ecosystem; but even within a biome are many areas that differ significantly.

Indeed, within the limited geographic area of a single township are usually several different kinds of ecosystems. A stream and its watershed, a forest, a salt marsh estuary, a freshwater pond, marsh, or swamp, a sand beach—each of these can be considered an ecosystem. These are probably the smallest ecosystems for practical consideration, though an aquarium or terrarium can be self-sustaining for a limited period (fig. 1).

Figure 2. — *Ecosystems are interrelated; what happens in one eventually affects what happens in others. What happens in the forest affects the pond, the estuary, and, finally, the ocean.*



Although ecosystems are relatively self-sustaining, they also are inseparably linked (fig. 2). Thus the nature and quality of the marine ecosystem are influenced by the materials flowing into it from the estuary, and the estuary is influenced by the materials originating farther inland. Similarly, biomes are influenced by climate—weather that is spawned or modified great distances away.

So, the processes of an ecosystem at one point on the earth's surface can affect the processes at all other points on the globe. This intimate interrelationship of seemingly diverse ecosystems has been brought sharply into focus in recent decades as pesticides and radioactive materials have spread to distant reaches of the biosphere.

IN YOUR ENVIRONMENTAL ARENA

☐ List some of the Playing Fields or ecosystems in your community.

☐ Trace your community's water supply from origin through use to disposal. Does it return to nature as clean as it left?

☐ What is the primary method of disposing of sewage in your community? Is any harm done to the environment? If so, what?

☐ How are solid wastes disposed of in your community? If by landfills or dumps, do they create a pollution problem? How long can the community continue to use this system? Is recycling a part of the present system? Should it be? Why?

☐ What are the major vegetational communities in your area?

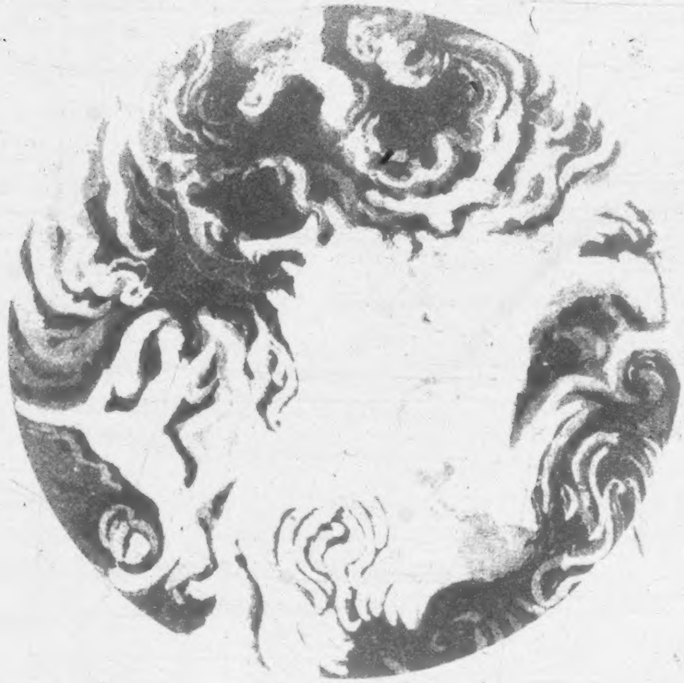
☐ What changes might have occurred in these communities in the past few decades? Why?

☐ List any major disturbances to the land in your area.

☐ What are the reasons for your community being established where it is? Do these reasons differ from those that might have been given by early settlers? Why?

☐ What are the sources of energy used in your community for home heating, for industry, for agriculture? Will there be enough energy from these sources for the community as it grows? What other sources of energy would work as economically for the community?

☐ Do you believe there is an energy crisis? Why? Why not?



The Environmental Gameboard

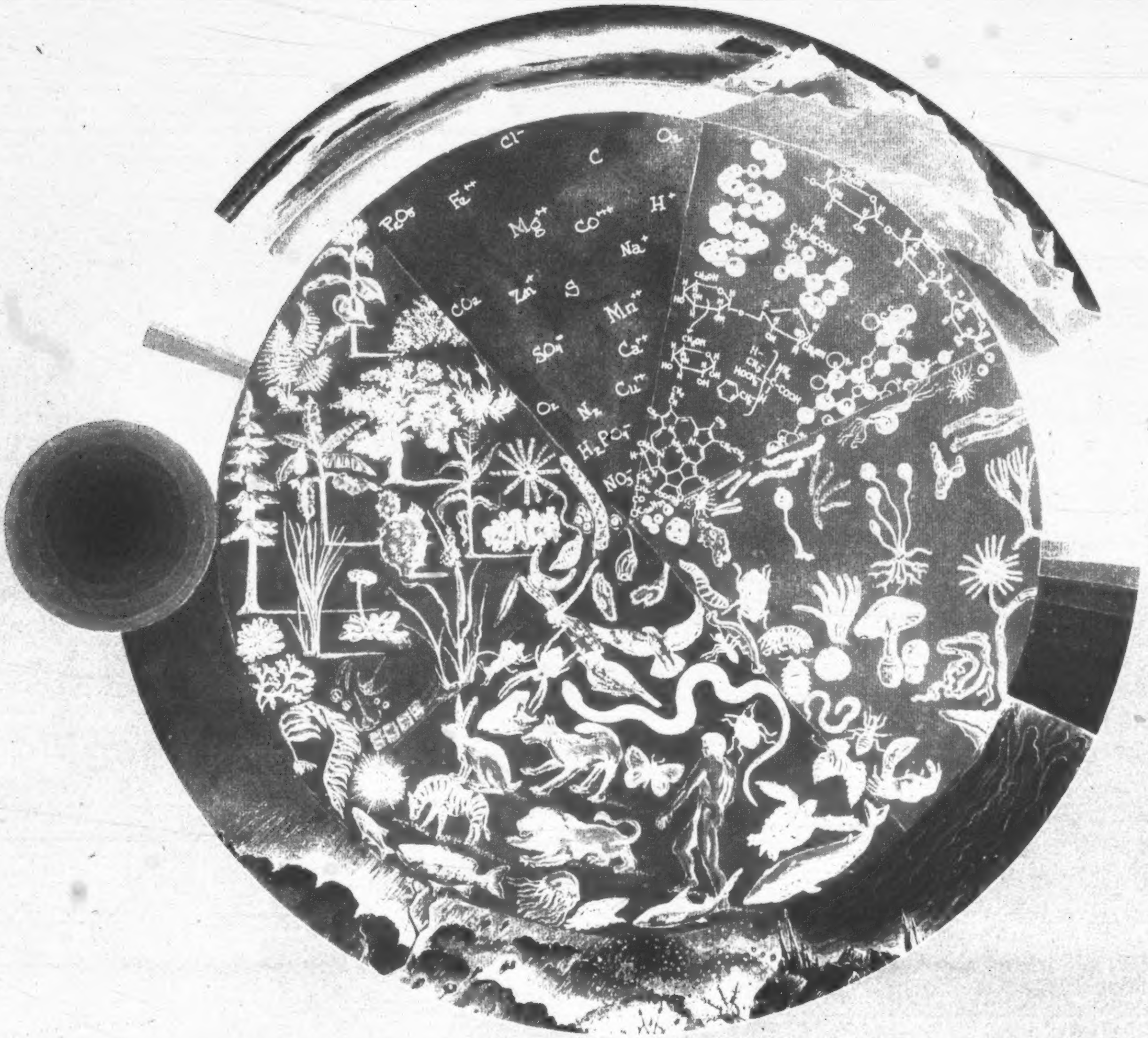
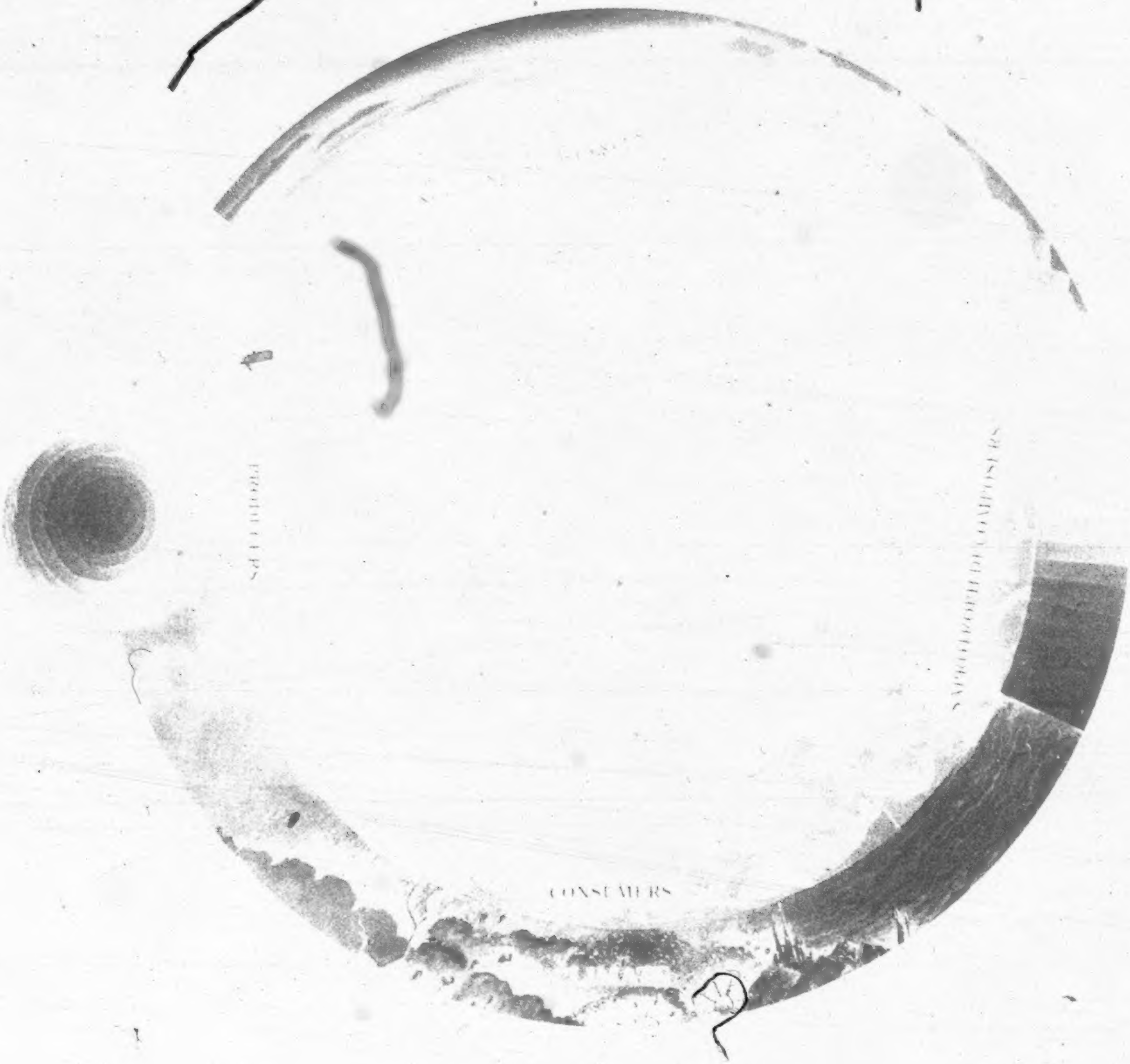
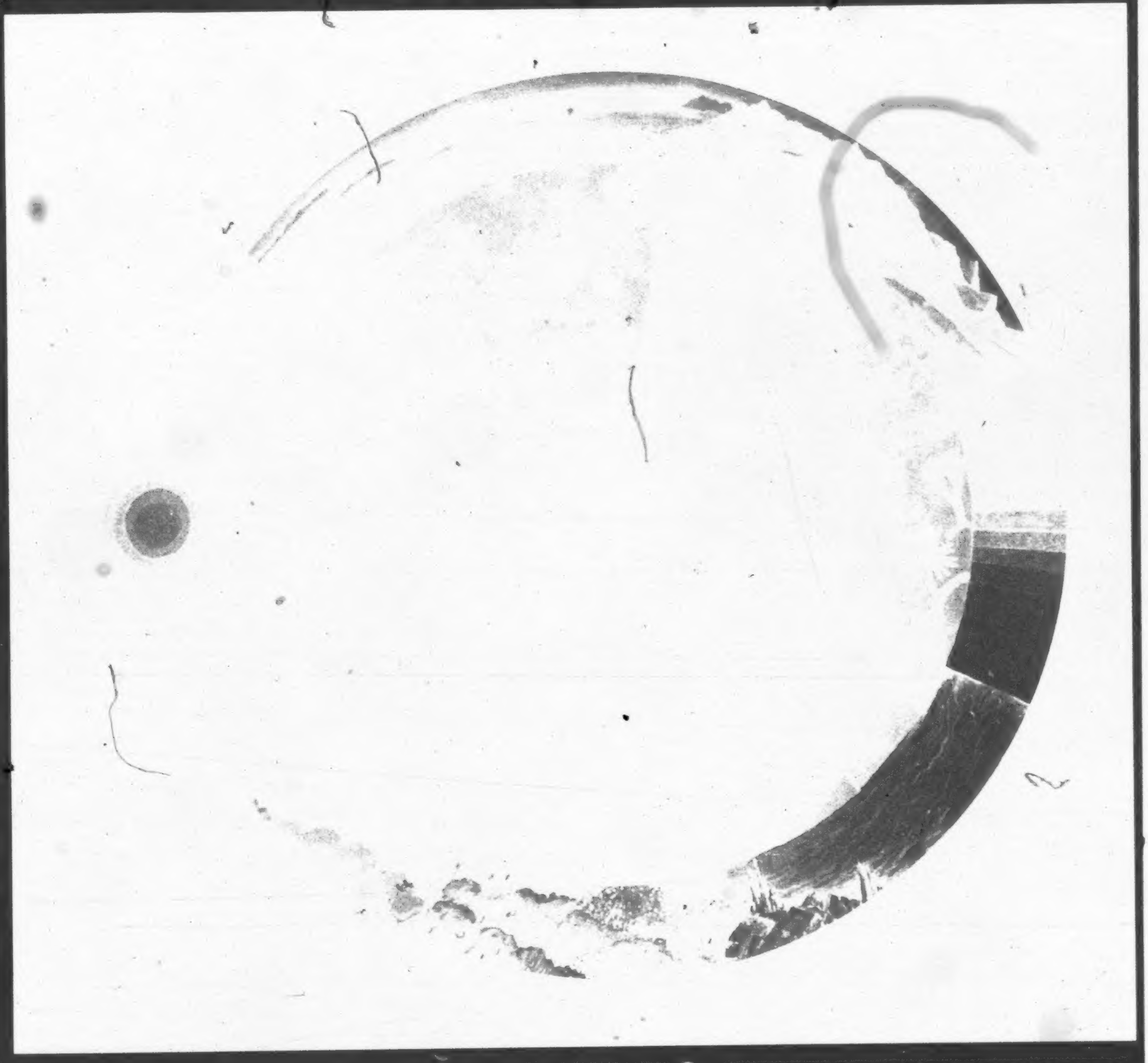

Cl⁻
C
O₂
P₂O₅
Fe⁺⁺
Mg⁺⁺
Co⁺⁺⁺
H⁺
Na⁺
CO₂
Zn⁺⁺
S
Mn⁺⁺
SO₄⁼
Ca⁺⁺
Cu⁺⁺
O₂
N₂
H₂PO₄⁻
NO₃⁻

Figure 3. —*The Players of the Game include the green plant Producers, the animal Consumers, the macro- and micro-saprotroph Decomposers, the Organic Compounds, Inorganic Substances, and Environmental Climate.*


PRODUCERS
SAPROTROPH DECOMPOSERS
CONSUMERS

II. THE PLAYERS

We've defined ecosystems as the Playing Fields or Environmental Arenas where living or *biotic* organisms interact with each other and with their nonliving or *abiotic* environment. These biotic and abiotic components (fig. 3) are the *Players* of the Game of the Environment. Included among the Players are the biotic green plant Producers, animal Consumers, and macro- and micro-saprotroph Decomposers, and the abiotic Organic Compounds, Inorganic Substances, and Environmental Climate. Like ecosystems, the Players are inseparably linked as they interact with each other.

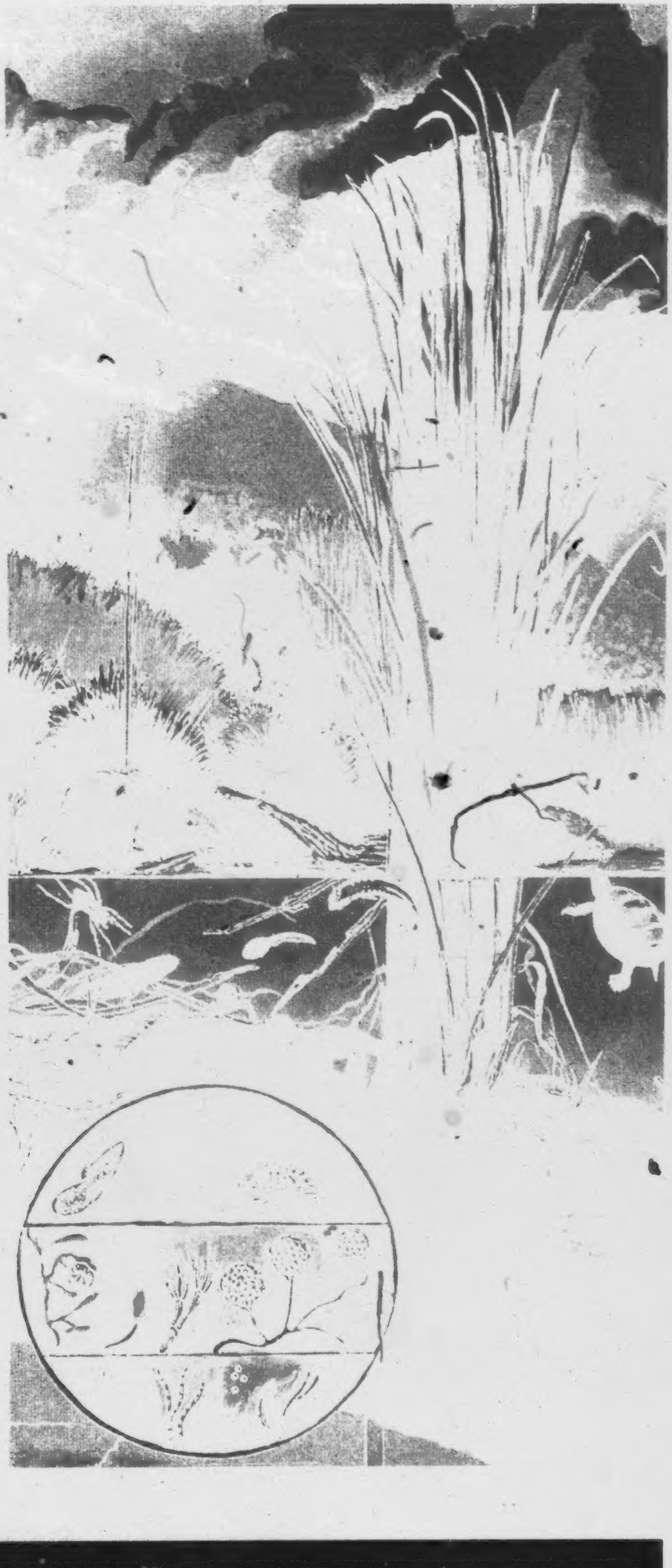


THE PRODUCERS

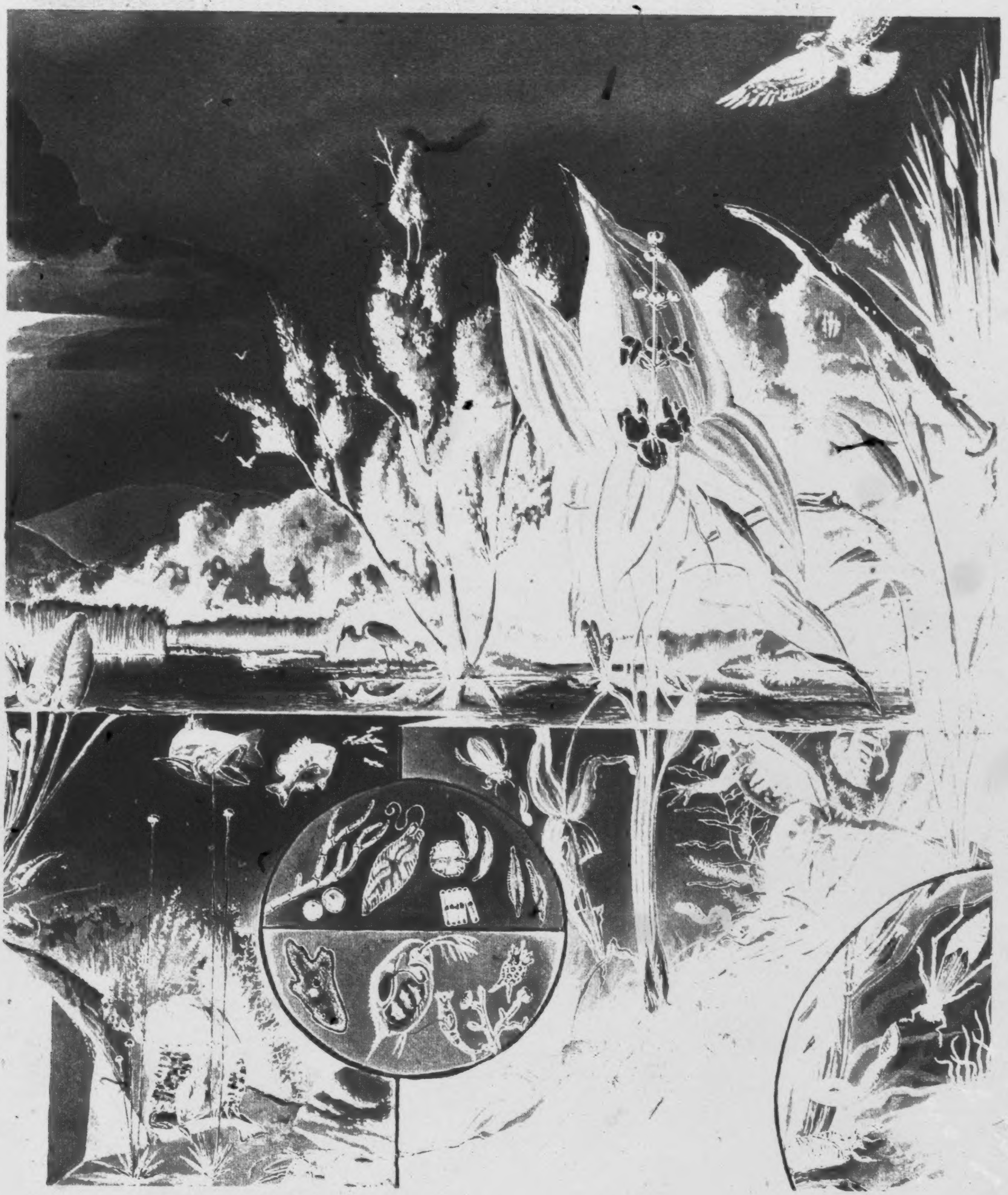
The *Producers* of a pond arena are *green plants* (fig. 4). They include *rooted plants* such as cattail and arrowhead (emergents), waterlilies and pondweeds (surface plants), watermilfoils (underwater plants), and tiny *floating plants* or *phytoplankton* (algae and diatoms) (fig. 4, top of center insert).

Rooted plants are abundant in shallow water near the edge of the pond; phytoplankton are distributed throughout the water as deep as sunlight can penetrate. In most large deep ponds and lakes and in the oceans, algae are the primary Producers; yet we often overlook them and their value to the system.

Figure 4. — *The green plant Producers of the Fresh Water Pond are shown in green.*



Fresh Water Pond Arena



In the terrestrial forest ecosystem (see Forest Arena illustration, p. 18), the Producers (fig. 5) play the same role as those in the pond: that is, they convert sunlight and carbon dioxide (CO_2) into food energy—sugars and other organic compounds—to "Fuel" themselves and the other living Players of the system. The green plant Producers of all ecosystems are called *autorophs;* this means self-nourishing. All other living components of the system are *heterotrophs* (other nourishing); they depend on the food-making producers directly or indirectly for their sustenance.

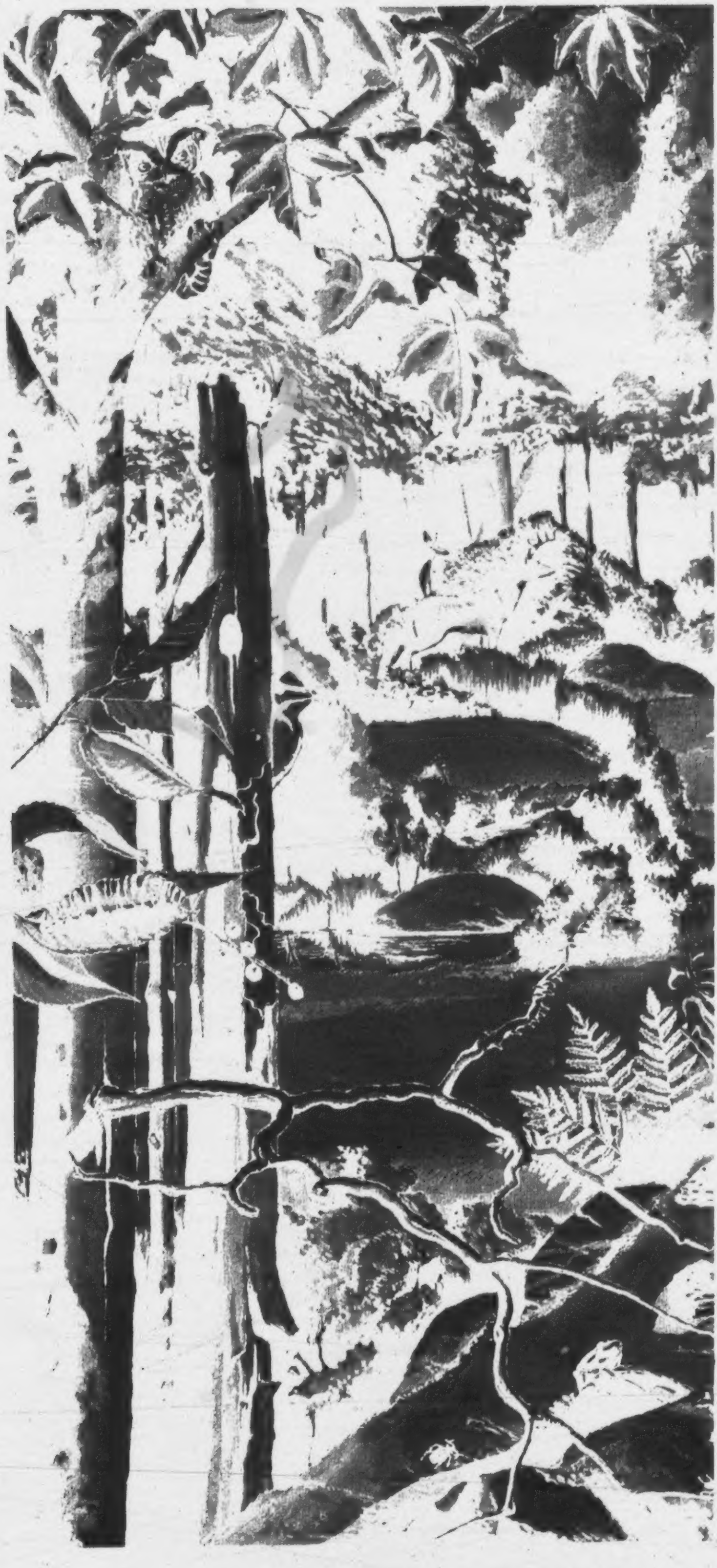
As the Producers of the pond are stratified or arranged in layers above, on, and below the water surface, so, too, are these Players in the forest arranged in layers or strata. There are usually three layers: The ground layer that includes mosses, herbs, or wildflowers and lichens; the shrub layer, including saplings; and the tree layer above. In some forests there are many tree layers; in others, algae, mosses, and lichens grow on trunks and branches of trees far above the ground and shrub layers.

Unlike the role played by algae in the aquatic ecosystem, the role of algae in the terrestrial ecosystem is of minor importance. Here, the large rooted plants dominate, not only as food makers, but also in stabilizing and modifying the earth's surface. Actually, all rooted plants, large and small, affect the water system and the quality of the earth's surface. Another major role of vegetation is to provide shelter for the *Consumers*.

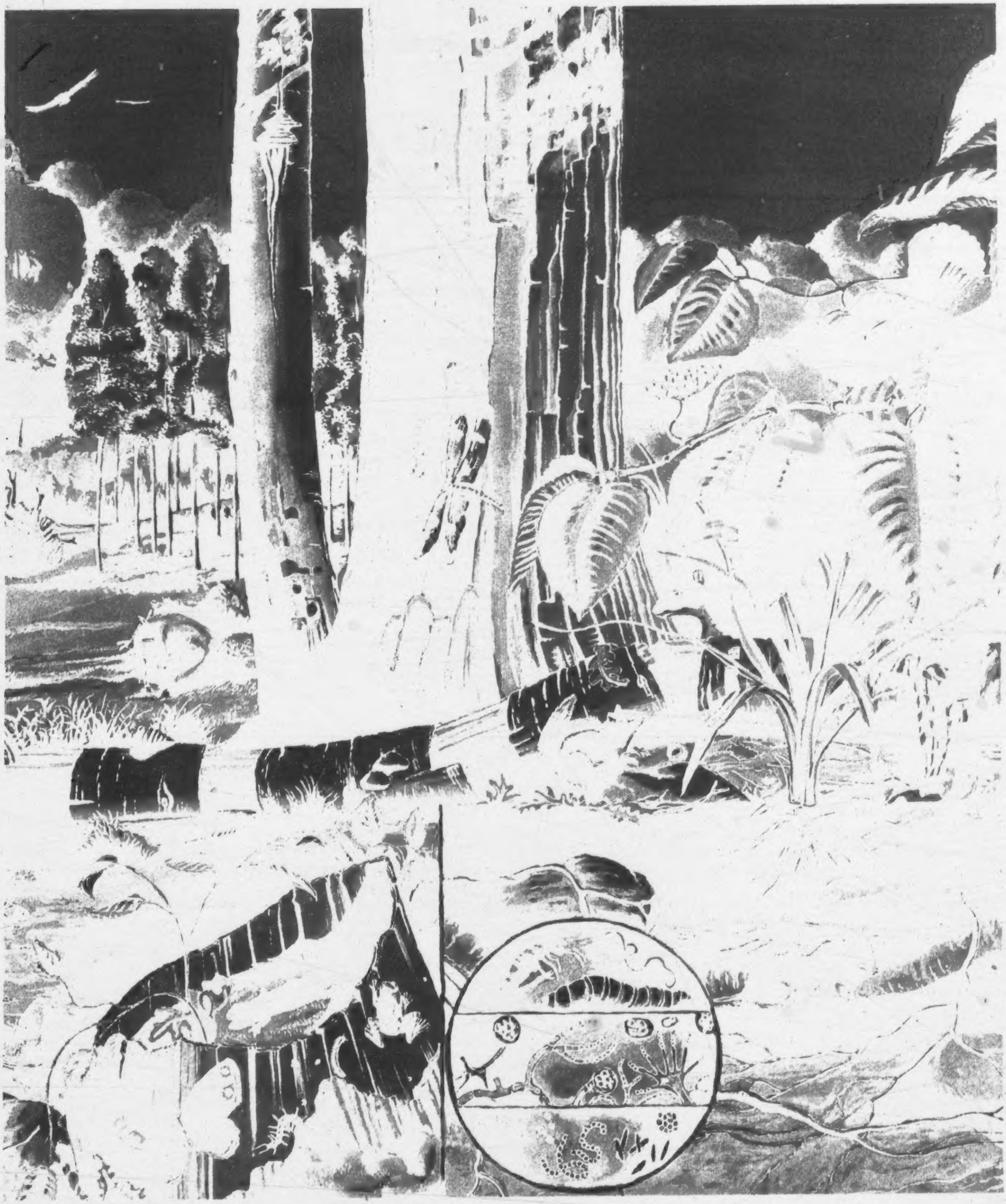
IN YOUR ENVIRONMENTAL ARENA

☐ List the Producer Players in two ecosystems of your community.

Figure 5. — *The green plant Forest Producers are shown in green.*



Forest Arena



THE CONSUMERS

The Consumer Players are the *animals* of the ecosystem. Animals that obtain their energy directly by grazing on plants are called *herbivores;* those that obtain energy indirectly by feeding on other animals are called *carnivores*. Some animals, called *omnivores,* eat both plants and animals. People are usually omnivores.

The "grazer" herbivores of the pond ecosystem are primarily the *zooplankton,* or tiny floating animals (fig. 6, bottom half of insert) but they also include some insects, snails, and higher forms of life such as frog tadpoles. On a higher level, muskrats feed exclusively on aquatic plants, especially cattail; and some waterfowl are important herbivores.

Figure 6. – *Some Consumers of the pond are shown in red.*

The terrestrial ecosystem contains a variety of animal Consumers. The herbivores include not only insects and small rodents but also large hoofed mammals (fig. 7). In the forest, birds can be important *primary* (herbivorous) and *secondary* (carnivorous) Consumers.

Figure 7.—*A few forest Consumers are shown in red.*

Classifying these Consumers according to their value to an ecosystem as *food* for other animals and as *consumers of food* (plants or animals) is a convenient way of studying the energy relationships between predator and prey and host and parasite. Consumers, then, occupy "food" or *trophic levels* and *consumer levels*.

For example, the "grazer" herbivores occupy the next higher food or trophic level after plants; but as plant eaters, these animals occupy the primary or first consumer level.

Carnivores that feed on plant-eating animals are on the third trophic level (and the secondary consumer level). These second level Consumers, in turn, are eaten by other carnivore Consumers at still higher levels.

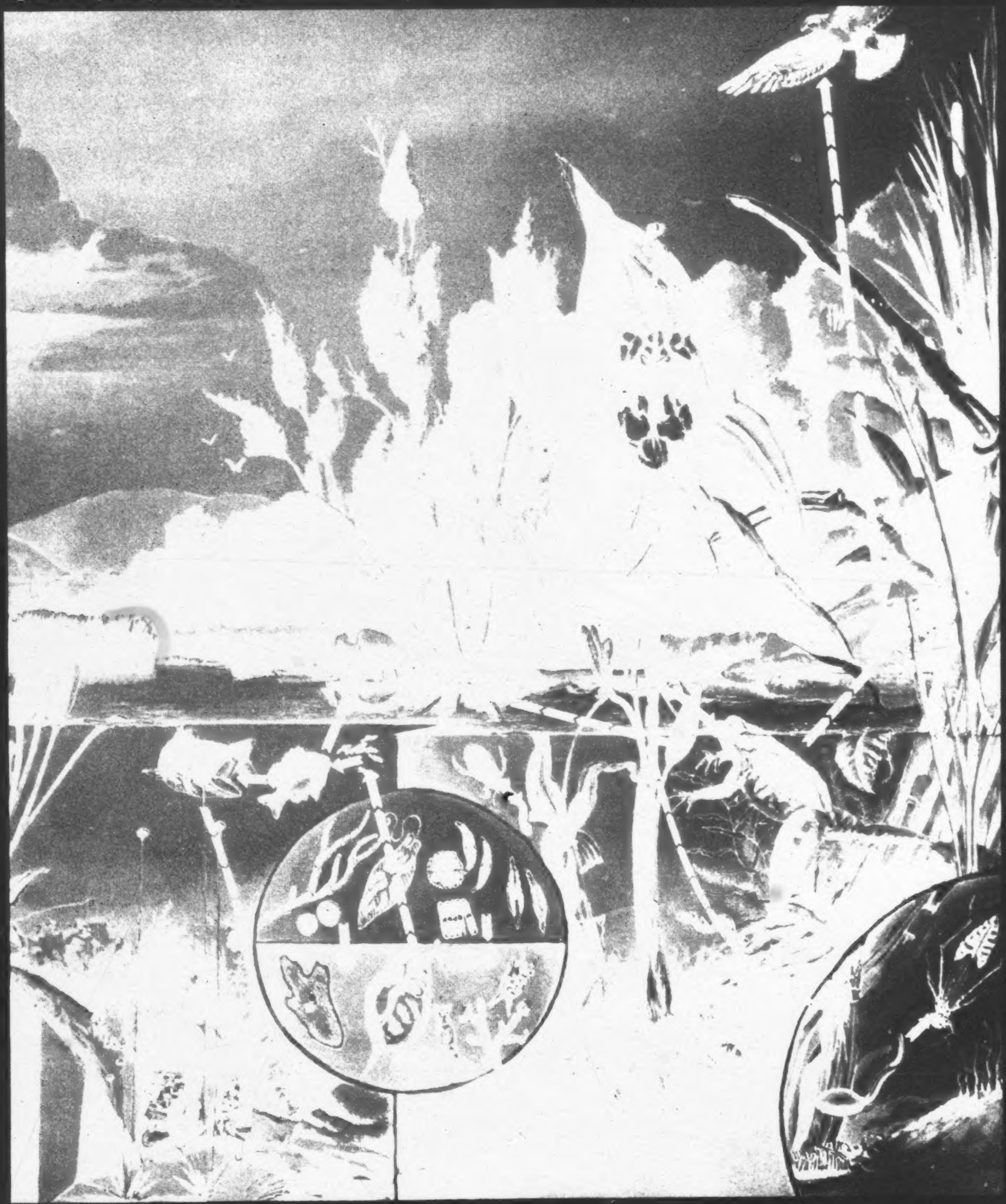
This transmission of food energy from one trophic level to the next higher level is called a *food chain*. Food chains are often interconnected with others to form a *food web*. (figs. 8 and 9).

In our pond Arena, animals such as frogs and toads are herbivorous as young, but they move up one or more trophic levels as adults. In the forest, birds and mammals of prey such as owls, hawks, and foxes occupy the highest trophic levels.

In the forest ecosystem, large amounts of the "woody" material produced by plants are low in food value, however there are Consumers that digest or use this material. These Consumers make up another set of living Players—the *Saprotrophs*.

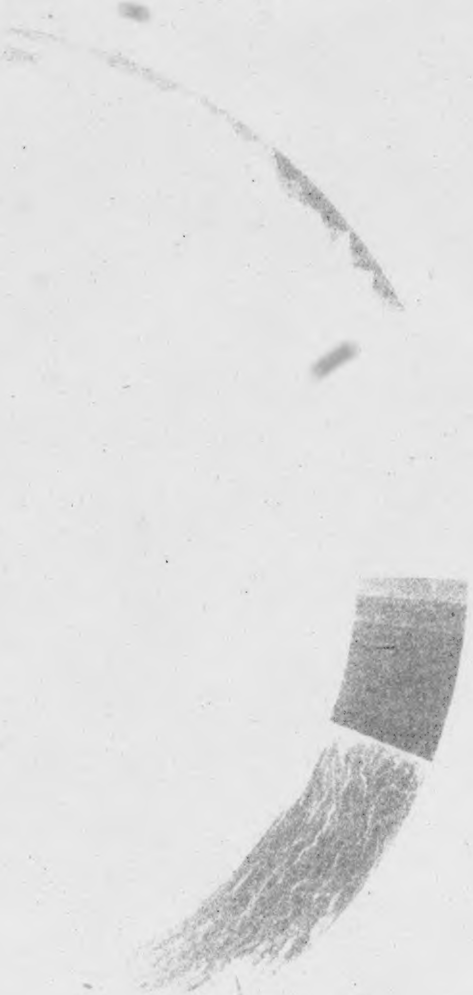
Figure 8.—*A portion of the forest food web.*

Figure 9. — *A partial pond food web.*



IN YOUR ENVIRONMENTAL ARENA

☐ List and describe the Consumer Players in an ecosystem in your area.
☐ Draw a food web with as many levels as possible for your ecosystem.



THE SAPROTROPHS: DECOMPOSER CONSUMERS

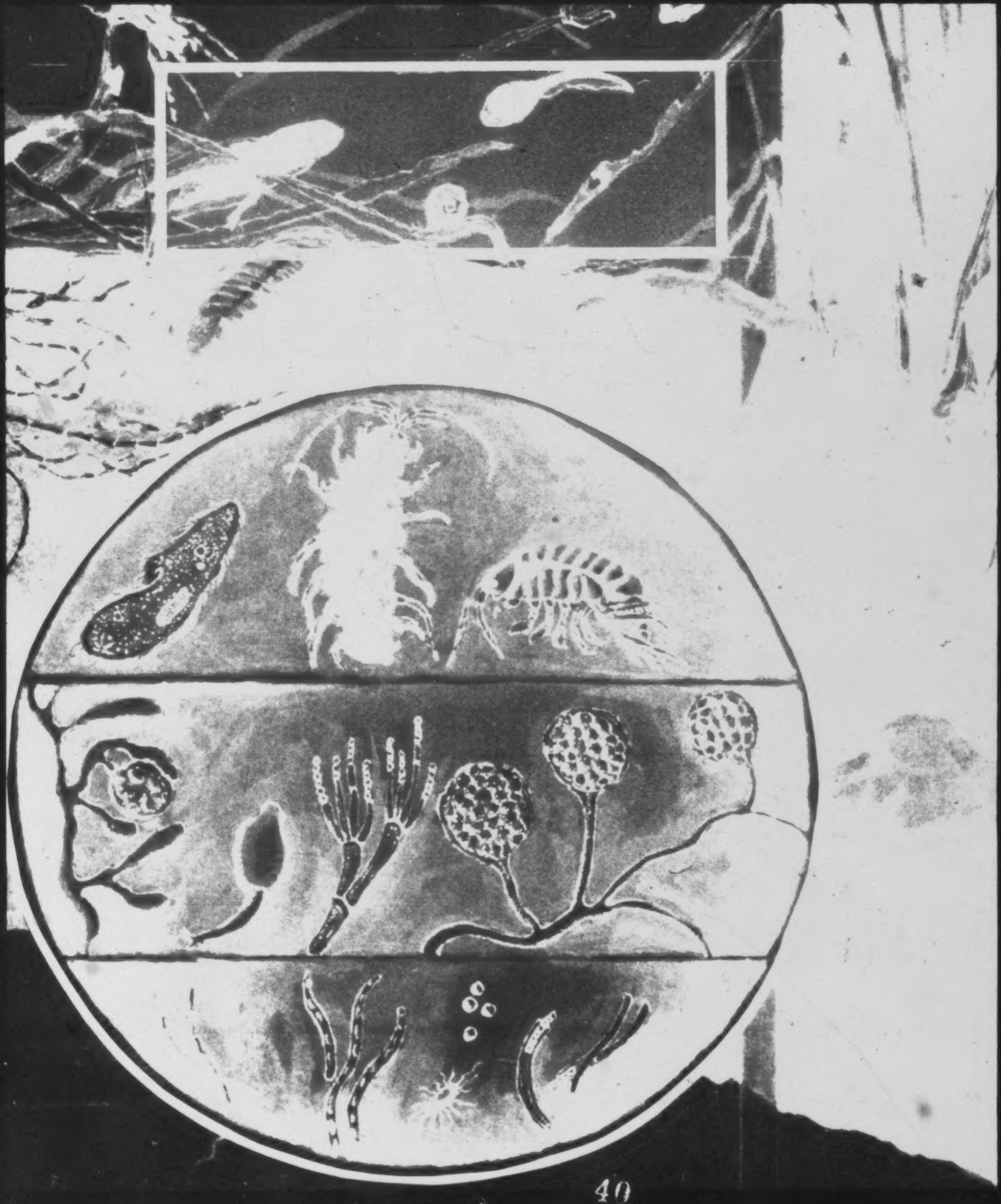
Saprotrophs subsist on the tissue of dead animals and plants (detritus). They include *macroconsumers*—certain insects, worms, and snails—that feed on this detritus—and the *microconsumers*—organisms of decomposition such as protozoa, bacteria, fungi, and actinomycetes. The Saprotrophs are important members of all ecosystems because they break down the complex organic molecules of protoplasm and cell walls into basic components that can be used again by the Producers.

Detritus of the aquatic ecosystem is more easily "digested" than that of the land system. In the water, therefore, the most important Saprotrophs are the macroconsumers or detritus feeders (fig. 10); the *decomposer* microorganisms that can digest cellulose and lignin of wood are the most important on land (fig. 11). If these organisms did not play the Game effectively, nutrients essential for growth of the plant Producers would soon be "locked up" in dead bodies and the Game of the Environment would come to an end.

IN YOUR ENVIRONMENTAL ARENA

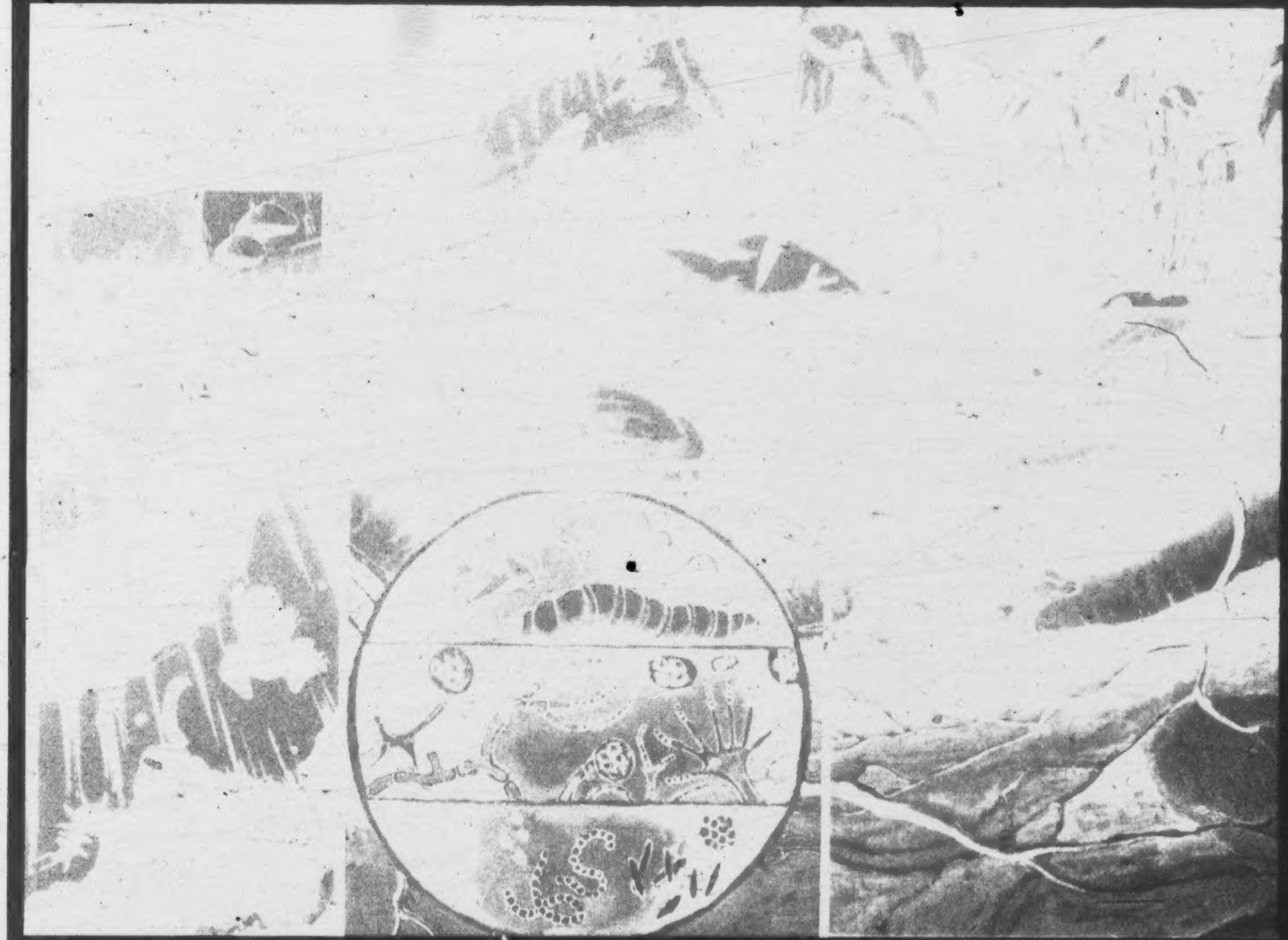
☐ List any evidence of Saprotrophs in an ecosystem in your community.
☐ List some of the ways that Saprotrophs are important to you in your daily activities.

Figure 10. — *Saprotrophs of the pond.*



The activities of the biotic Players suggest that they are intimately interrelated with their nonliving environment. As we stated earlier, the abiotic components of the environment are also Players of the Game. We can divide them into three categories: *Organic Compounds, Inorganic Substances,* and the components of the *Environmental Climate.*

Figure 11.—*Some forest Saprotrophs.*



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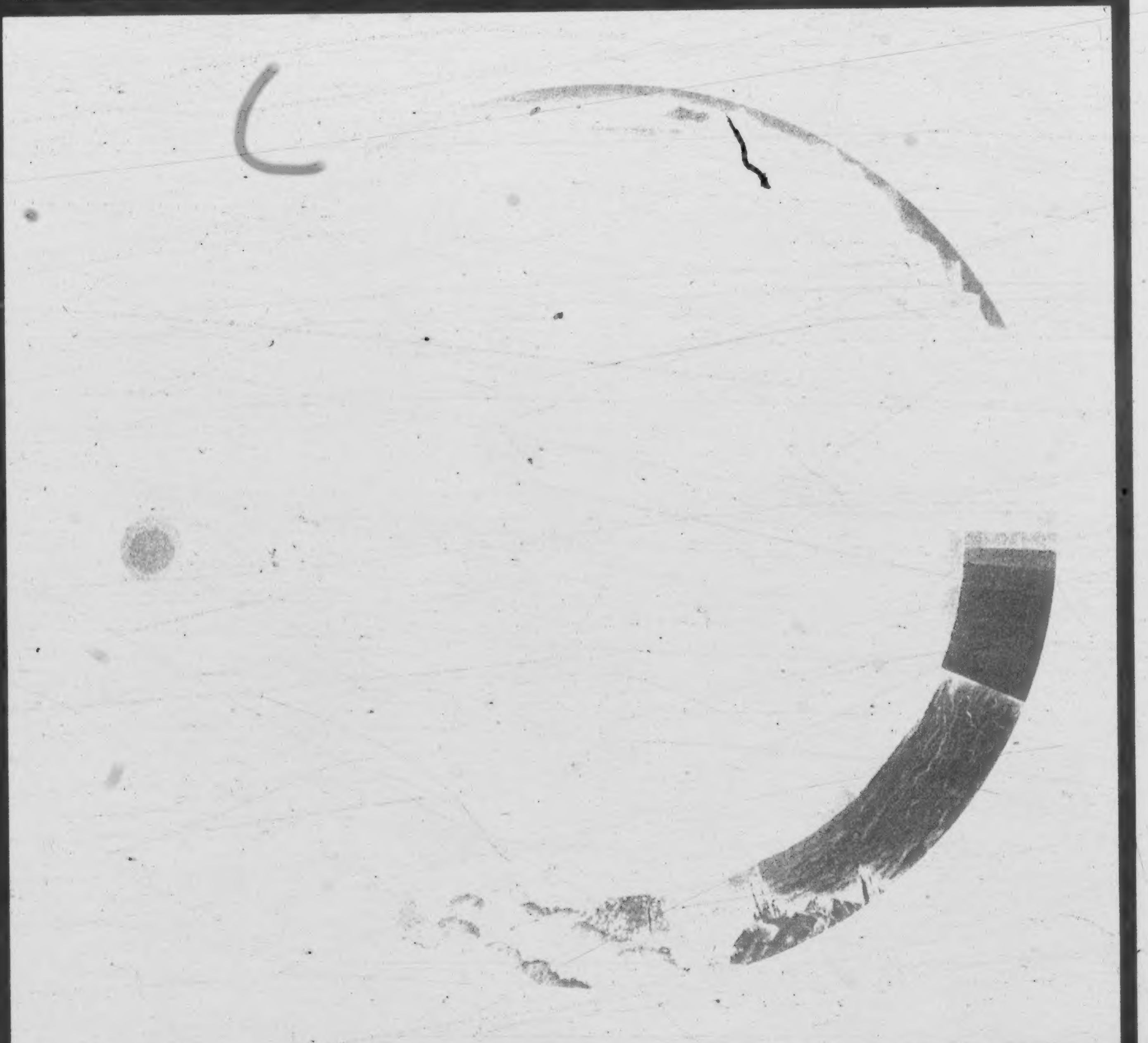
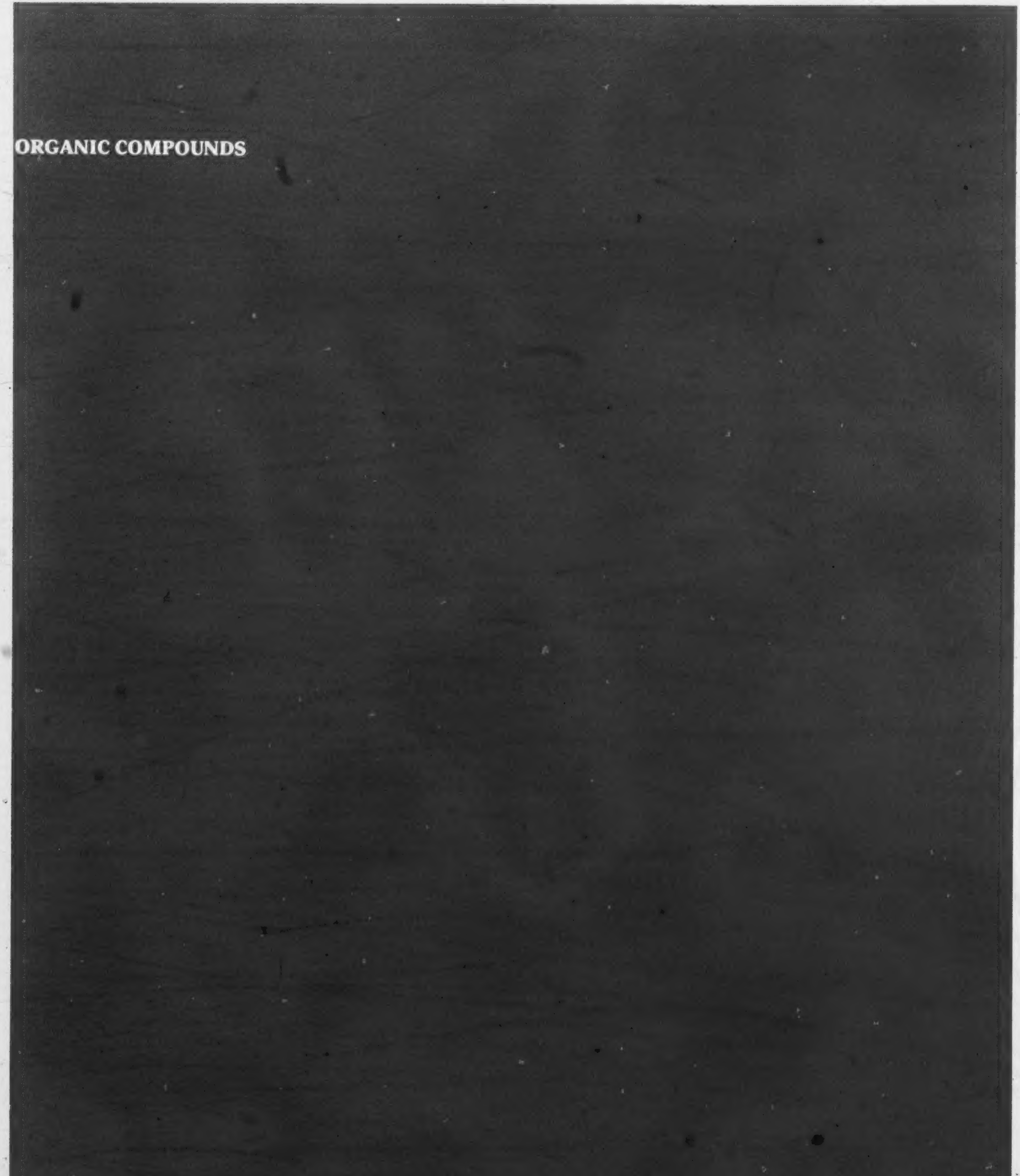


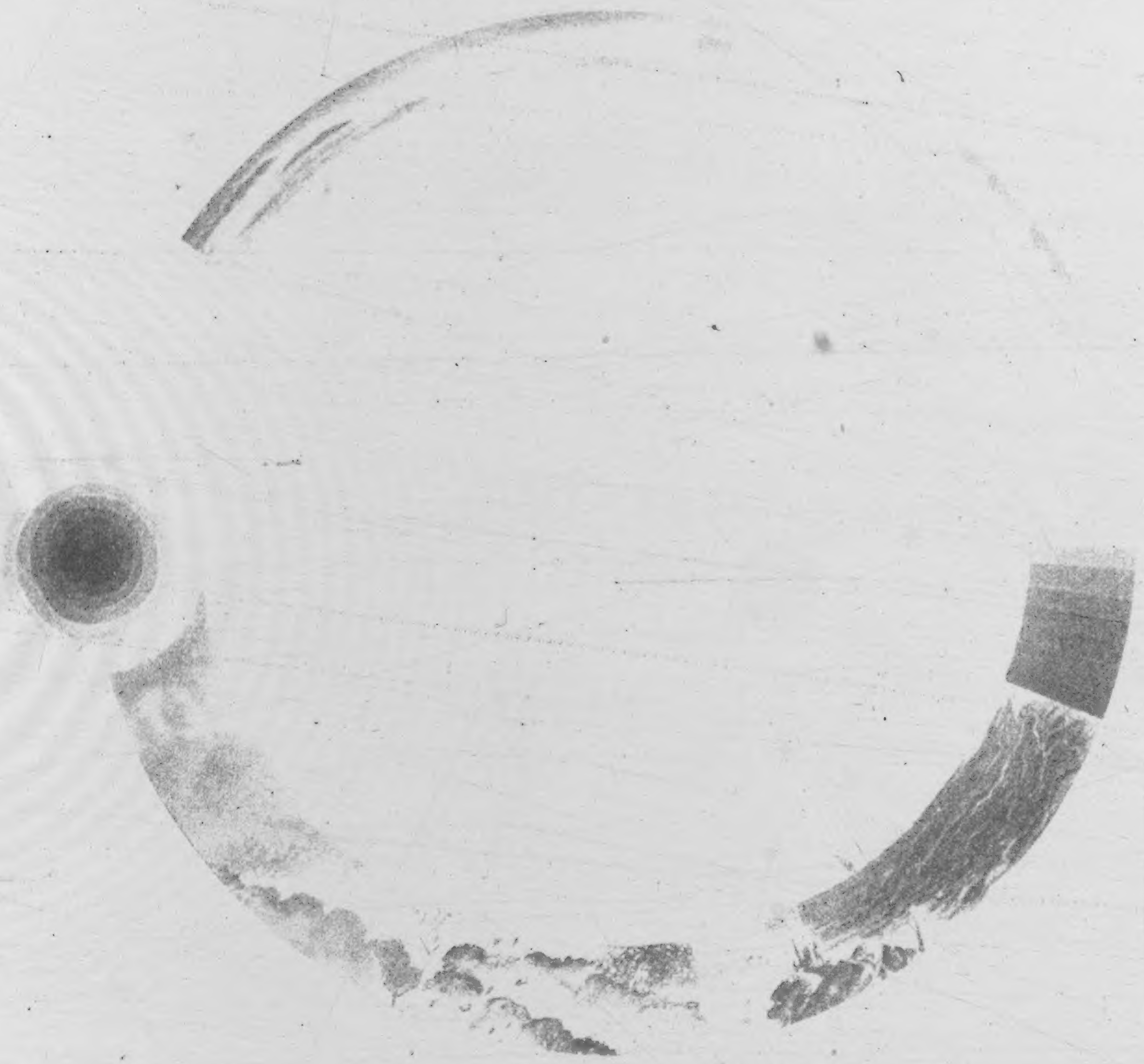
32

12

ORGANIC COMPOUNDS



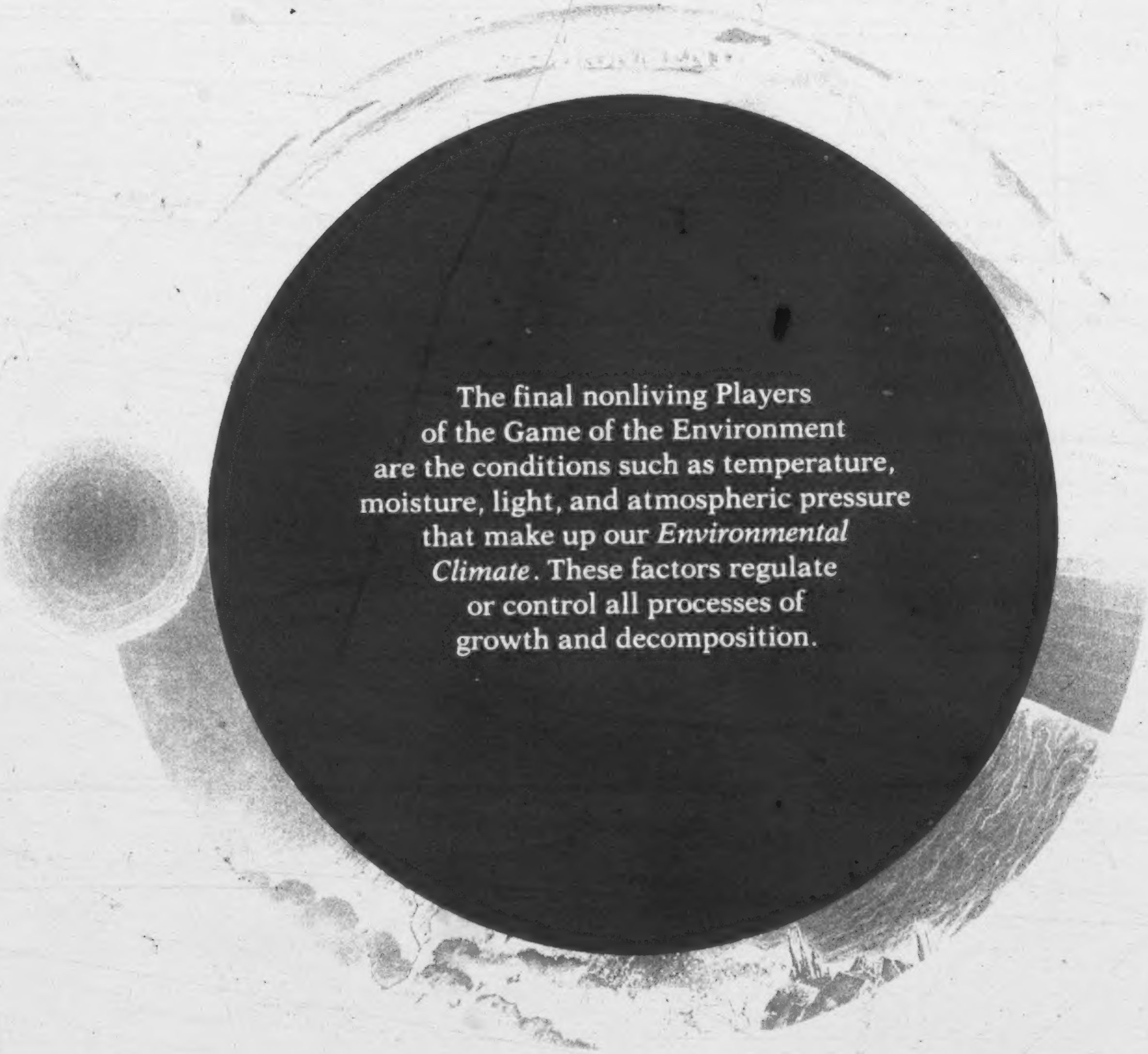
The Organic Compounds include carbohydrates, proteins, fats, and other compounds of plants and animals. Some of these compounds are easily digested by many kinds of organisms; some have molecules that resist breakdown by all but a few organisms with specially adapted enzyme systems.



INORGANIC SUBSTANCES

Primarily through the action of bacteria, the Organic Compounds are reduced to Inorganic Substances—elements such as phosphorus (P_2O_5), nitrogen (N_2), and sulfur (S) that can be recycled through the ecosystem beginning with the plant Producers. Sometimes these inorganic elements cannot be used directly, but must be recombined (again by the actions of special groups of bacteria) into other molecules. Thus plants use phosphorus as phosphates (H_2PO_4), nitrogen as nitrates (NO_3), and sulfur as sulfates (SO_4).

So the organisms in a natural ecosystem, interdependent because of food chain energy relationships, also depend on one another because they require growth substances that can be supplied only through the interactions of other organisms and the abiotic environment. The process by which essential materials are cycled between the living and nonliving Players is called biogeochemical cycling (see page 53). Nonessential and harmful materials also cycle through the biosphere.



The final nonliving Players
of the Game of the Environment
are the conditions such as temperature,
moisture, light, and atmospheric pressure
that make up our *Environmental
Climate*. These factors regulate
or control all processes of
growth and decomposition.

ENVIRONMENTAL CLIMATE

In our pond ecosystem, the reproductive rate of the algal Producers and, therefore, of most of the other organisms, is strongly influenced by the temperature and chemical composition of the water, the depth of the water, the amount of shade from overhanging and floating vegetation, and by the general location and topography of the pond.

Similarly, in the forest, the species of plants that occur, how well they grow, and the types and numbers of animals they support directly reflect the nature of the soil, the annual distribution of rainfall, the length of the growing season, and many other factors of the physical nonliving environment.

IN YOUR ENVIRONMENTAL ARENA

☐ What factors of the environmental climate are especially important influences on plants and animals in your area?

III. RULES OF THE GAME

The *Rules* that govern or regulate the Game of the Environment are broad ecological principles applicable to all ecosystems. There are many of these principles or biological Rules, but of paramount importance are those that relate to:

☐ *One-way flow of energy through a system.*
☐ *Cycling of essential elements within systems.*

ENERGY FLOW RULES OF THE GAME

We on earth are entirely dependent on the sun for our energy—and we are but a way-station in the relentless path of energy's one-way flow from the sun to outer space. It is only because the green plant Producers have the fantastic and unique ability to use this light energy to convert carbon dioxide and water into sugars that we and all other life can exist. The constant rain of radiation energy on the earth is balanced by a nearly equal amount of heat energy that is returned from the earth to space. It is in the tissues—the protoplasm—of living and dead organisms that energy can be stored for awhile on earth as potential food energy for the Consumer Players, or for use by people as fuel.

First energy rule

Energy can neither be created nor destroyed, only converted from one form to another. This fact is the First Energy Rule; it is known as the *First Law of Thermodynamics.*

Photosynthesis and respiration

Plants accomplish their life-giving function by *photosynthesis*. This remarkable example of the First Energy Rule occurs when the green chlorophyll of leaves converts carbon dioxide, water, and light energy into sugars and oxygen. A general equation for this process, the most important one in the world, is:

In the presence of

CO_2 **(carbon dioxide)** **and** **H_2O** **(water)**

This, then, is how the sun's energy is converted into potential food energy for growth. But unless the substances thus formed are used, no growth can occur.

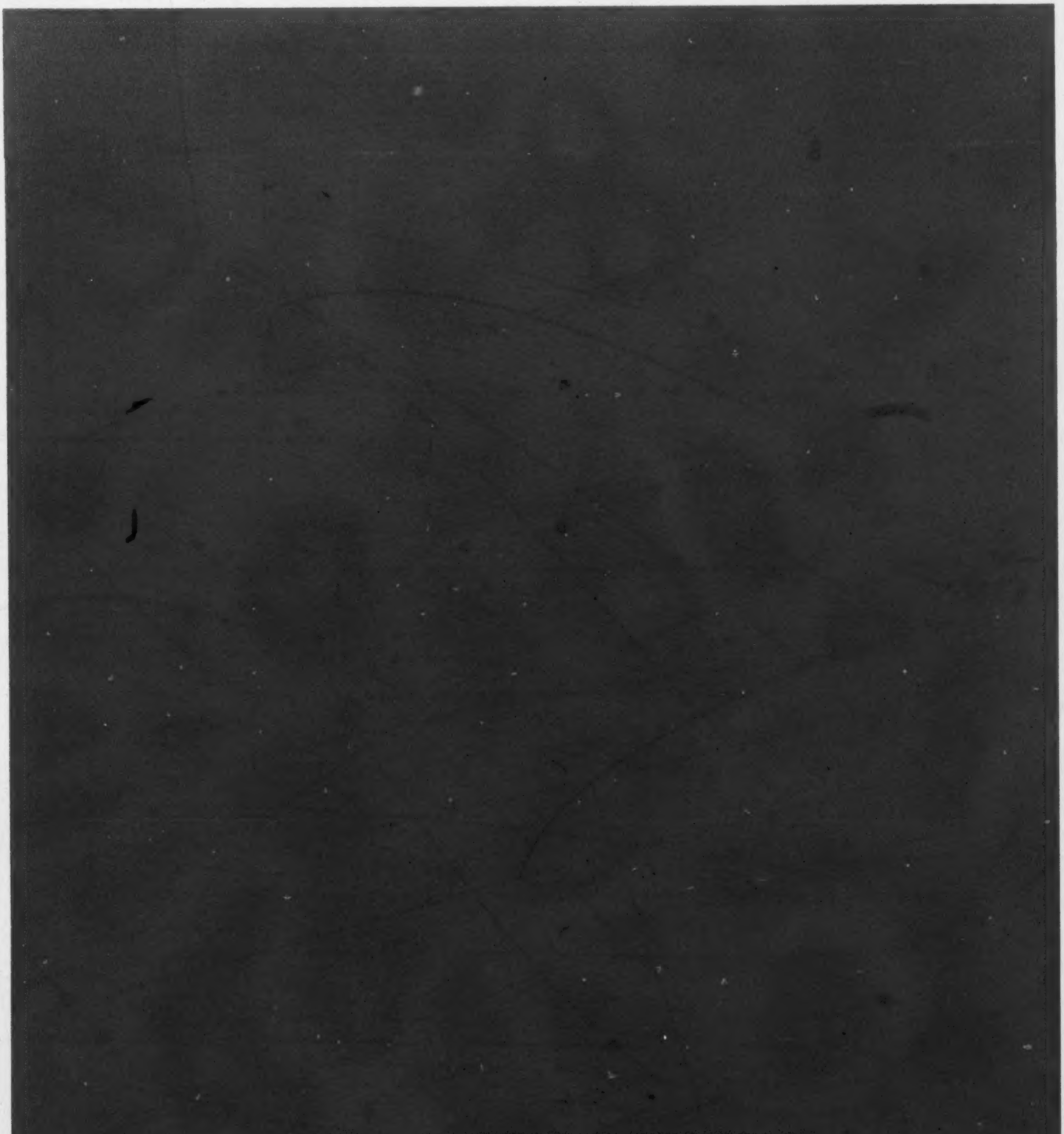
The process of breaking down the food produced by photosynthesis, called *respiration*, is the way that all higher organisms obtain their energy. Complete *aerobic respiration* (in the presence of oxygen) yields carbon dioxide, water, and cell material; if the process is incomplete, Organic Compounds that still contain energy remain. This energy may be used later by other organisms.

Each year on earth, about 100 billion tons of organic matter are produced through photosynthesis. And a large amount is oxidized back to carbon dioxide and water through respiration (removal of O_2 and release of CO_2) by living organisms. But some organic matter is tied up in standing trees and a small amount is buried and fossilized. The *fixation* or *incorporation* of carbon dioxide in plant tissues has helped increase oxygen in the earth's atmosphere to levels that allowed higher forms of life that breathe oxygen to evolve.

trees and a small amount is buried and fossilized. The *fixation* or *incorporation* of carbon dioxide in plant tissues has helped increase oxygen in the earth's atmosphere to levels that allowed higher forms of life that breathe oxygen to evolve.

The tremendous surplus of organic matter—accumulated over the eons and fossilized as coal and other fossil fuels—constitutes the world's "reserve bank" of carbon dioxide. Burning these fuels and speeding up the decomposition of certain organic substances that resist natural breakdown (through farming and draining wetlands) can materially alter the CO_2-O_2 balance of the atmosphere.

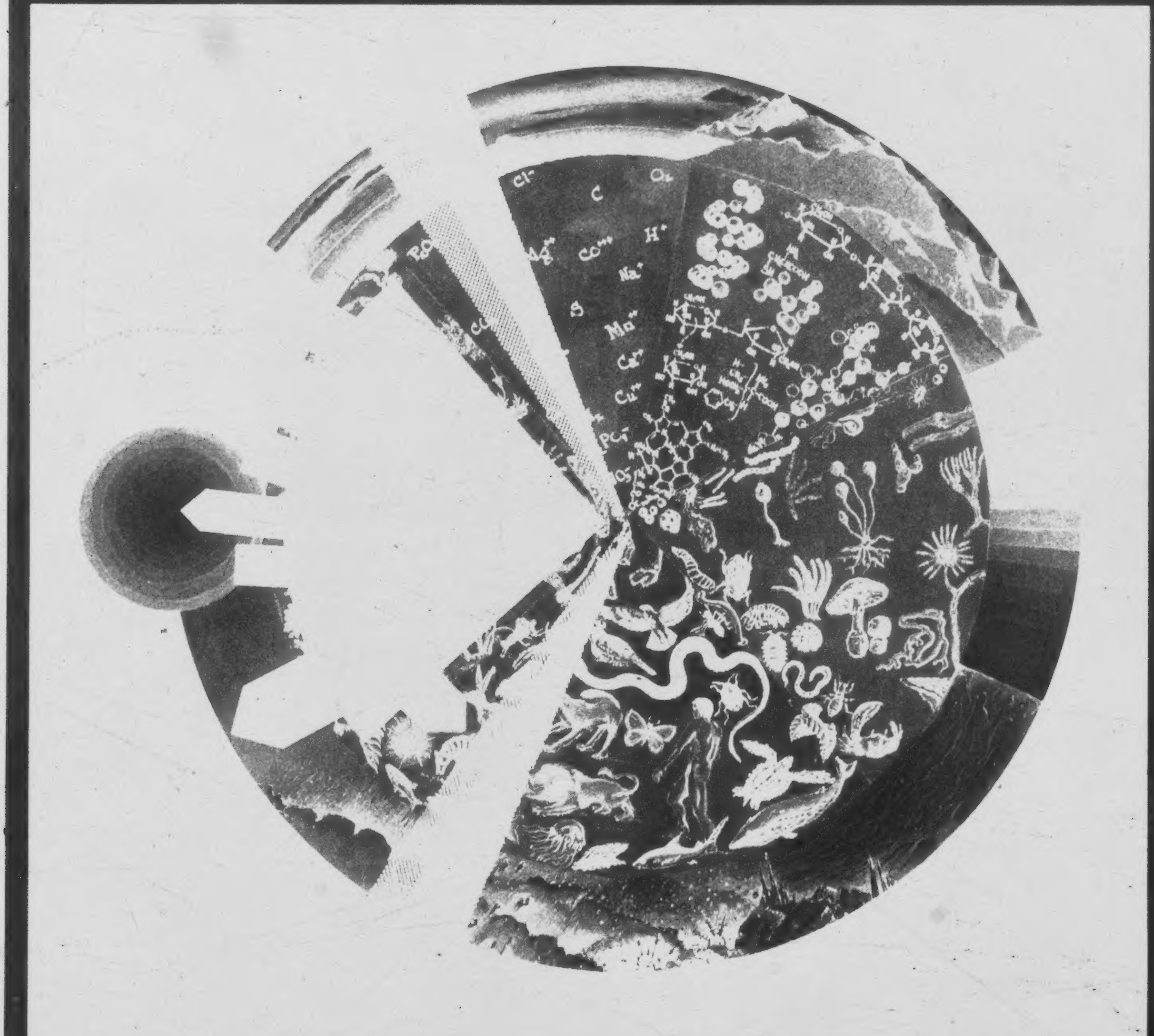
many levels as possible for your ecosystem.



Solar radiation—sunlight—reaches the biosphere at a constant rate of 2 gram (g) calories per square centimeter (cm^2) per minute, but only about two-thirds of this radiation reaches the ground. Of this light, 45 percent is visible, 45 percent is infrared, and 10 percent is ultraviolet. Plants use primarily the visible light from red and blue wavelengths in *photosynthesis* (food making), and they absorb some of the light from the long, far infrared wavelengths (fig. 12). And, while small amounts of green light and near infrared wave lengths are also absorbed and utilized by plants in important ways, most is reflected.

activities.

Figure 12. — *The sun's energy is converted by green plants to food energy.* Red arrows: *Light energy absorbed and utilized by plants. This includes blue and small amounts of green (1), red and small quantities of near infrared (2), and some far red (3) wavelengths.* Green outline and arrow: *net potential food energy produced through photosynthesis.* Blue arrows: *Energy reflected as light or heat into space.*



One-way flow of energy

The food chains shown in figures 8 and 9 point out some pathways along which masses of food energy pass through the ecosystem. What is not shown is the amount of food energy required to sustain one or all of the individuals at a trophic level; nor do these figures show the amount of heat energy that, generated in the maintenance of each organism, is radiated to space.

The different-size arrows in figure 13 represent the relative amount of food energy used for growth and maintenance (respiration), or that is stored by Consumers at each trophic level for use at the next higher level, or that is dispersed to space as heat.

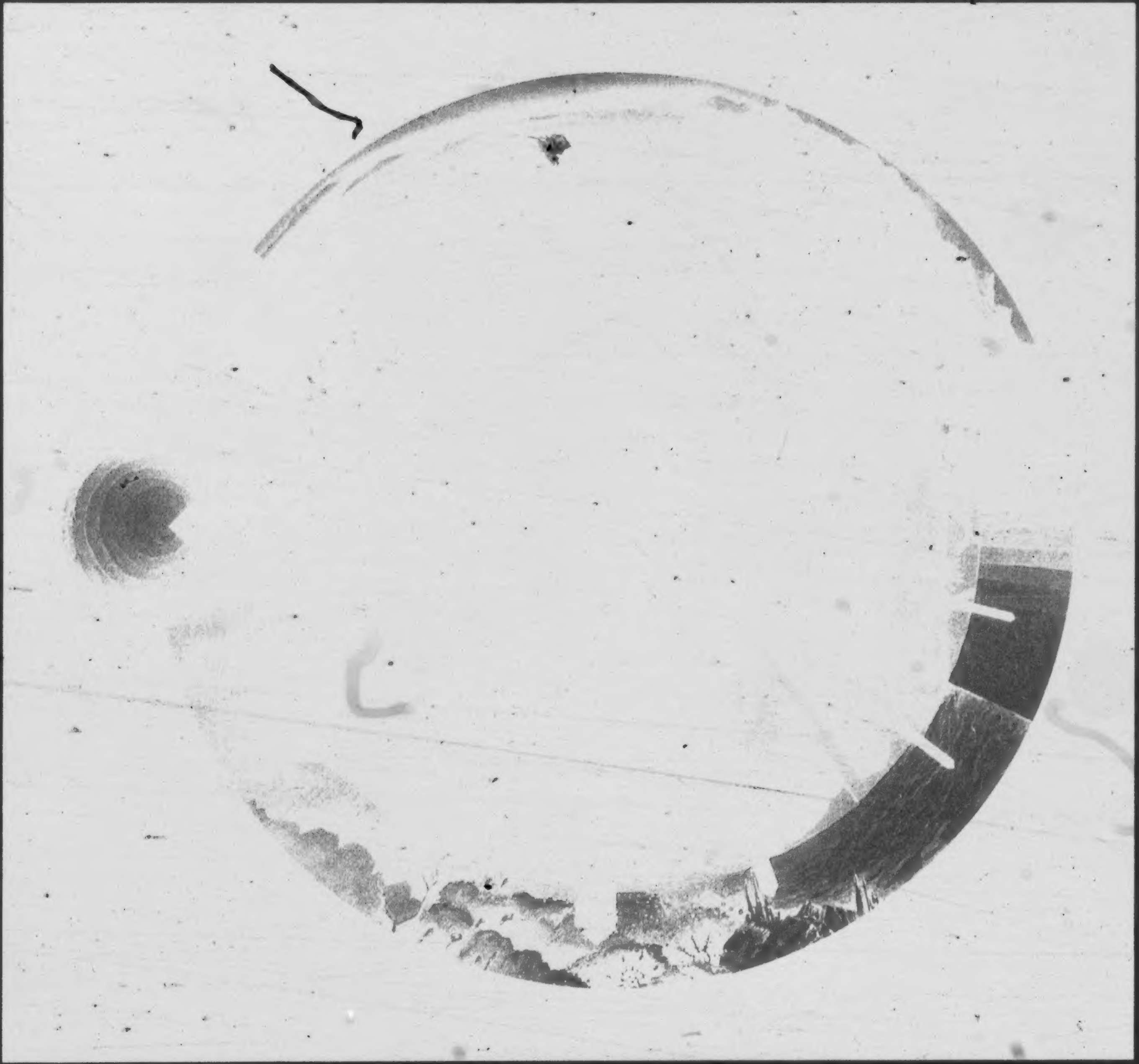
Second energy rule

At each step in the flow of energy from one organism to another—from one trophic level to another—a great amount of potential chemical energy (food) is converted or degraded to heat to enable a small part to be reestablished as potential chemical energy (new protoplasm) in order to maintain the life of that second organism. The natural tendency, therefore, is for all light and chemical energy to eventually be degraded to and distributed evenly as heat energy. This transformation of energy from a concentrated state to a dispersed state comprises the Second Rule; it is known as the *Second Law of Thermodynamics*.

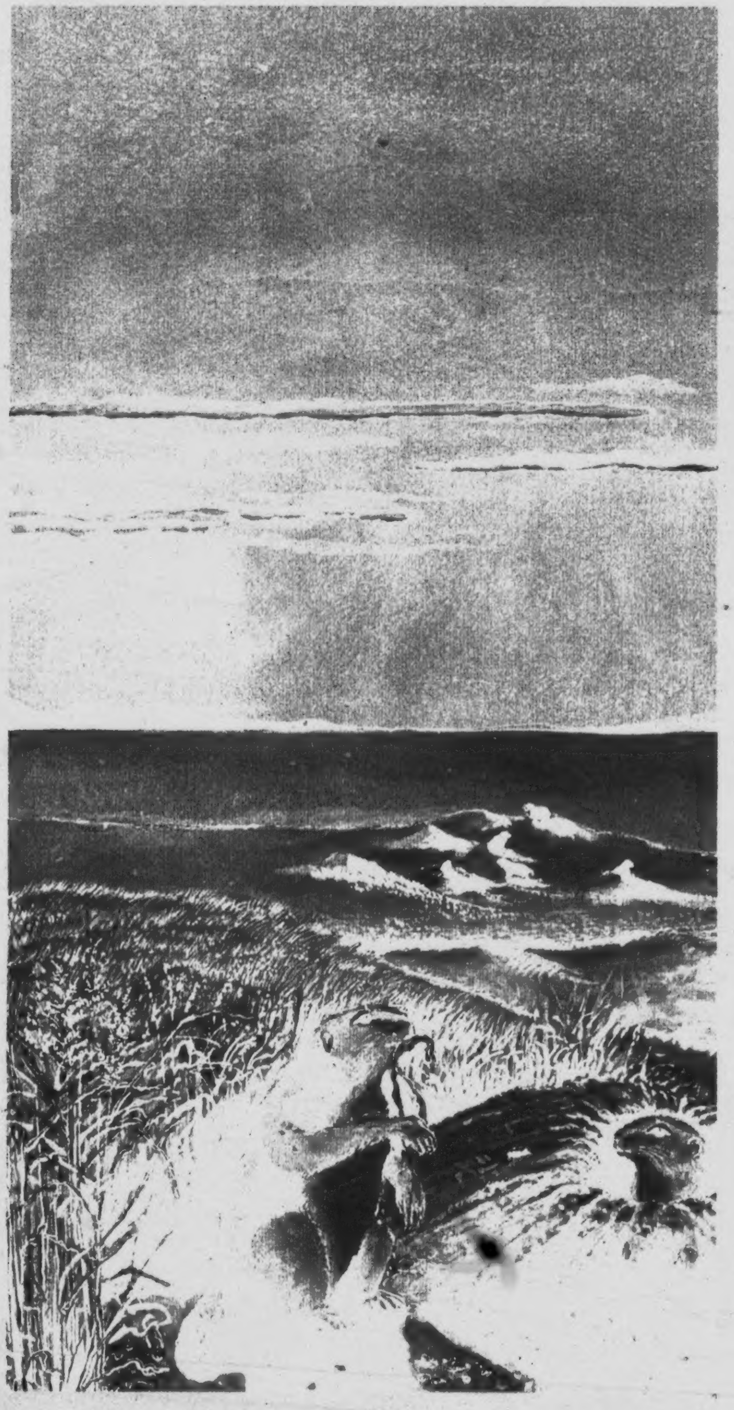
IN YOUR ENVIRONMENTAL ARENA

☐ Draw an energy flow diagram for an ecosystem near you. This could be your yard, a park, a garden, or a vacant lot. Include as many food levels as possible.

Figure 13. — *The one-way flow of energy through the ecosystem. Energy enters the system as light* (red arrows), *is transferred within the system as chemical food* (green mass and arrows), *and exits the system as heat* (blue arrows). *It does not recycle.*



The living Players of the system—the grass Producers; the prairie dog, black-footed ferret, and prairie falcon Consumers; and the Saprotroph Decomposer organisms—comprise an energy food web. Prairie dogs are the sole energy source of the black-footed ferret, a species on the brink of extinction. Populations of these predators declined sharply as the vast prairie dog towns were fragmented or destroyed.



Energy Flow through a Prairie Ecosystem

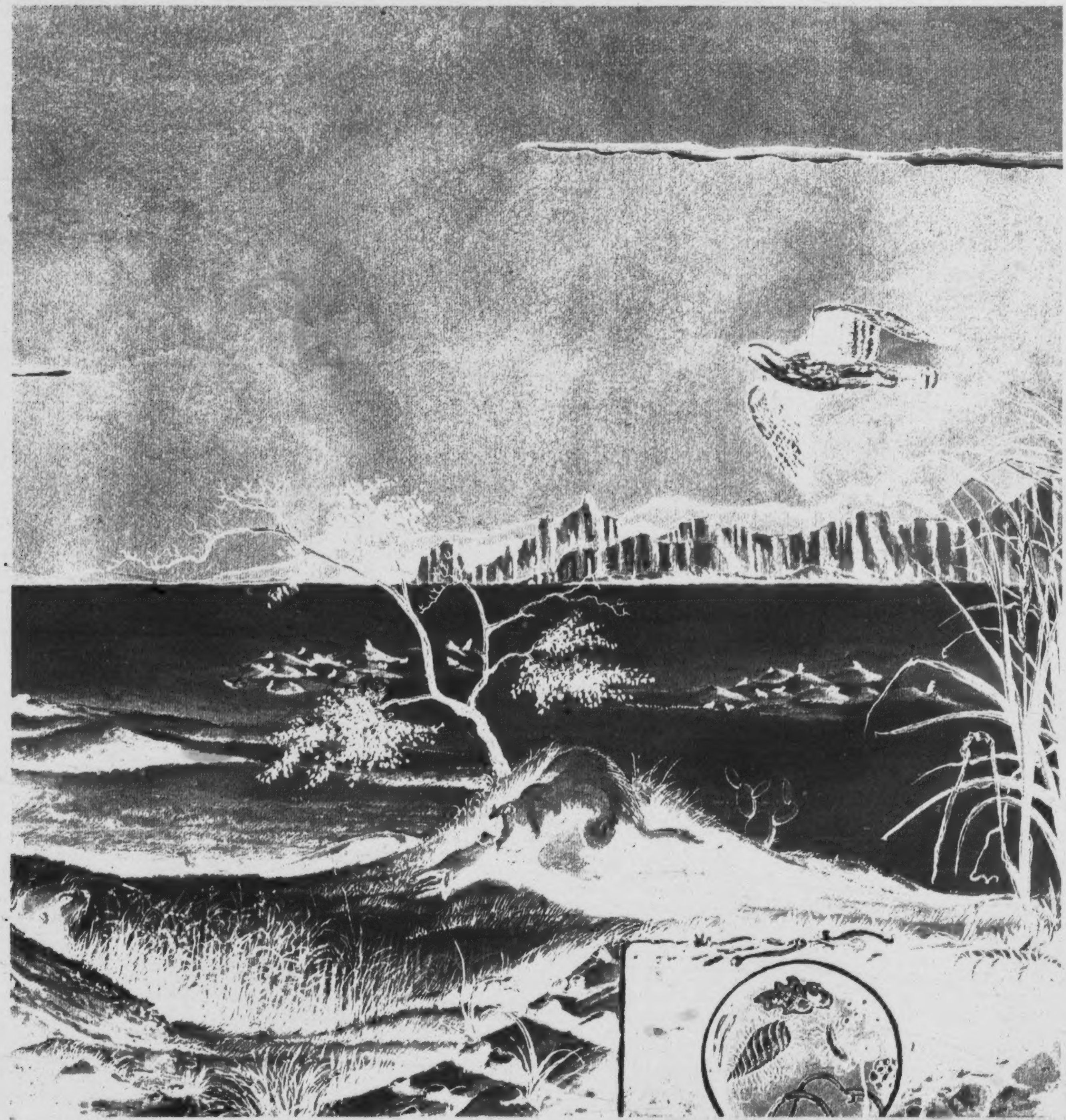
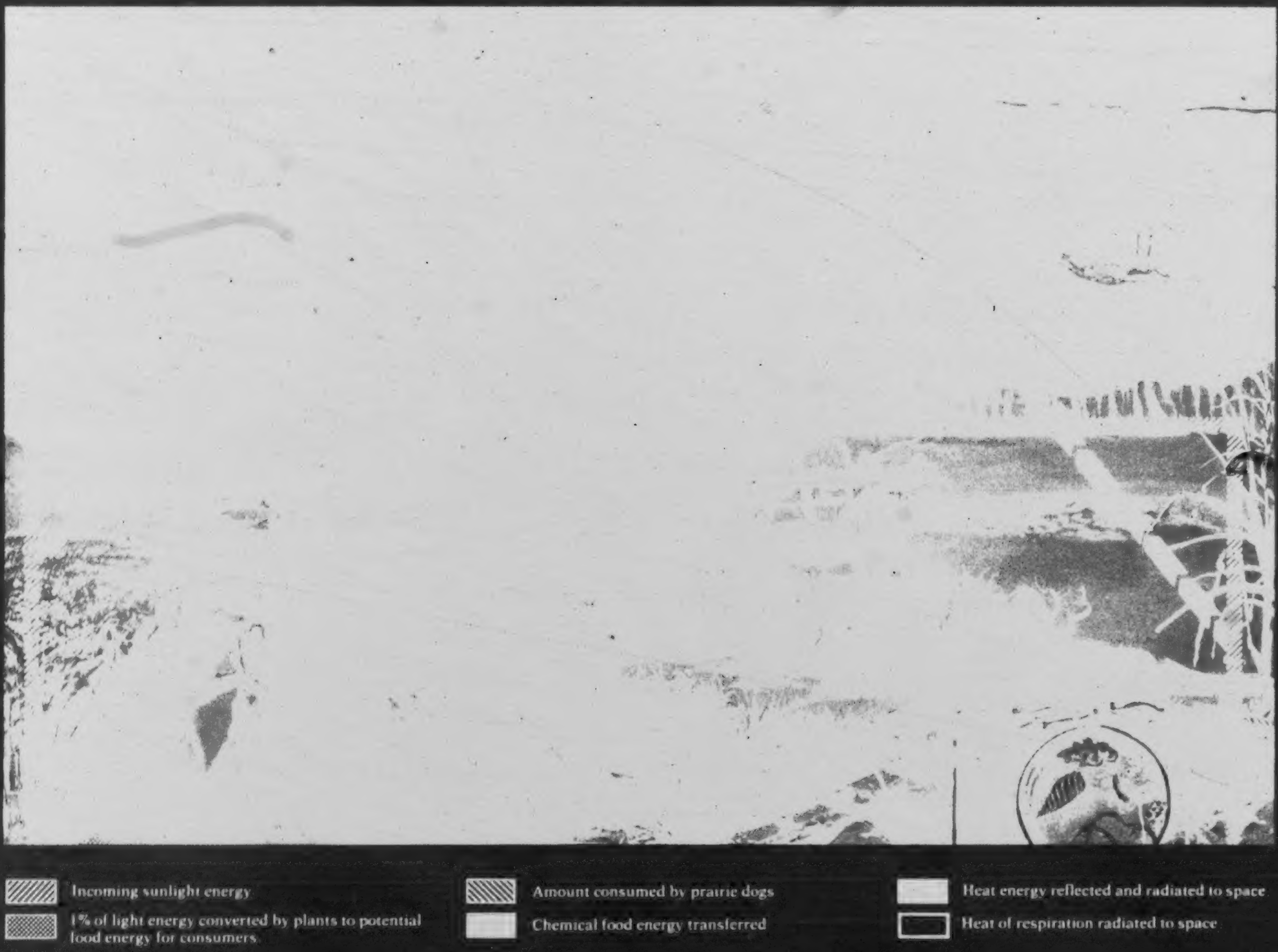


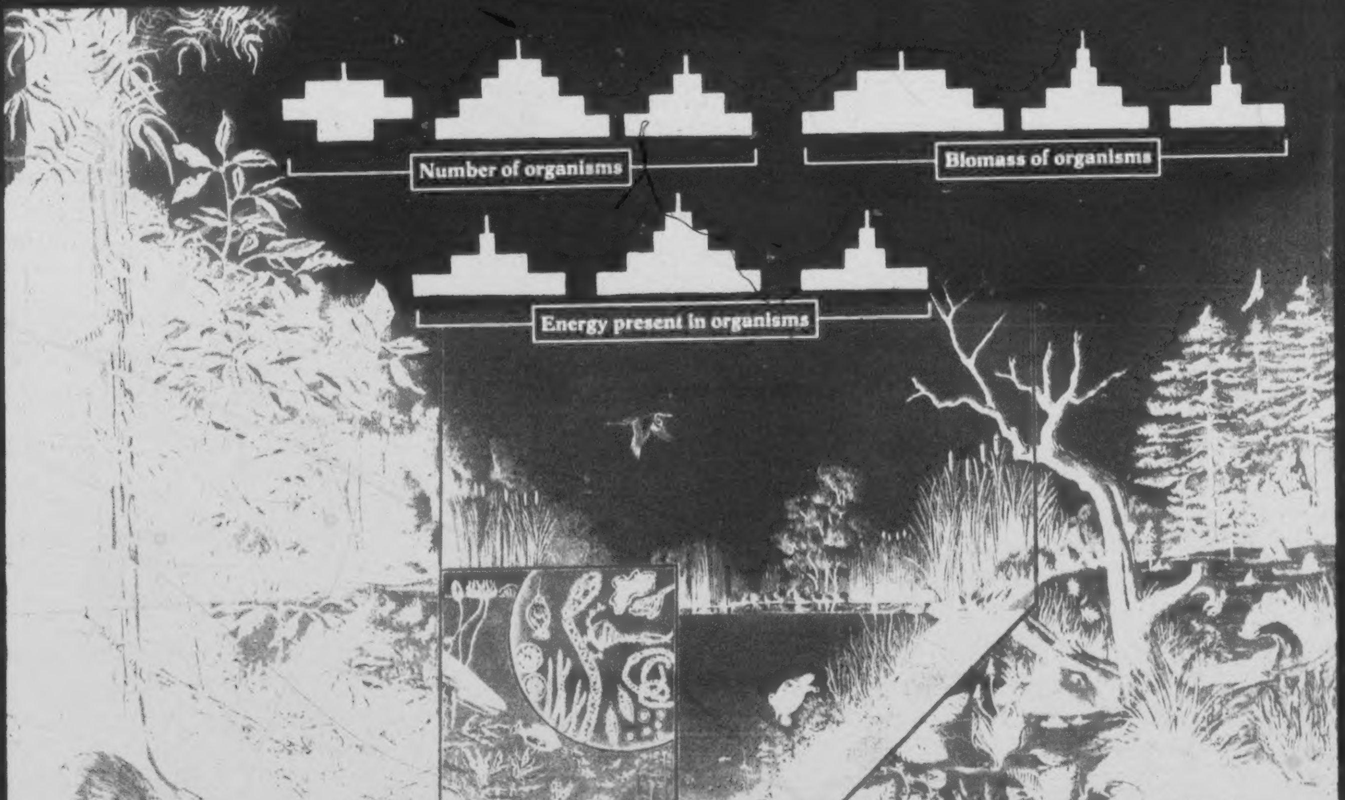
Figure 14. — *The path of energy flow through a prairie ecosystem. Red arrow shows sunlight energy coming in; green arrows, food energy being passed from plants to animals; and blue arrows, heat energy being dispersed to space.*


▨ Incoming sunlight energy
▩ 1% of light energy converted by plants to potential food energy for consumers
▧ Amount consumed by prairie dogs
☐ Chemical food energy transferred
☐ Heat energy reflected and radiated to space
☐ Heat of respiration radiated to space

An example of energy flow through a prairie ecosystem is shown in figure 14. In this Arena, light energy on prairie grasses (prairie cordgrass and wedgegrass) is shown by the red arrow. The bulk of light energy is reflected or is reradiated to space as heat (blue arrow). The plant Producers use about 1 percent of the light energy (wedge of 1 percent) to manufacture protoplasm and cell material and for respiration. Only a portion of the energy used by the Producer grasses is converted to potential food energy for use by the Consumer prairie dogs (green arrow), and only a portion of that small amount is actually consumed.

Much of the food energy consumed by the prairie dog is used to keep the animal warm *(respiration)* and is dispersed to space as heat. The small amount that is converted into prairie-dog tissues is available to its Consumers — primarily the black-footed ferret and, occasionally, the prairie falcon. These animals, in turn, convert most of this food energy to heat energy in respiration, but a small portion is stored in their new tissues. If there are no predators for these animals (if they are at the top of their food chain), their dead bodies (and those uneaten bodies at lower trophic levels) along with the unused portions of the prairie dogs (for example, bones and feces) are decomposed by the decomposer Saprotrophs. The respiration of the decomposer Players ultimately transfers to space, as heat energy, the last vestiges of the energy that entered the system as sunlight.

Figure 15. — *Ecological pyramids of numbers, biomass, and energy for a forest, a shallow pond, and an "old field."*


Number of organisms
Biomass of organisms
Energy present in organisms

Trophic level energy relationships

The relationships between trophic levels are of vital interest. How much acreage of a particular forage species must be grown to sustain a certain number of animals; how many parasites must be released to control a noxious insect; how many predators are necessary to maintain rodent populations at levels that will prevent unacceptable grain crop losses; or conversely, how many prey species are required to support viable populations of predators? These are some of the questions of trophic level relationships.

Ecological pyramids

One way of showing these relationships is by using *ecological pyramids*. In figure 15, the shape of hypothetical pyramids of *numbers* (individual organisms), of *biomass* (total mass (weight) of organisms per unit area), and of *energy* (flow from one trophic level to the next) are compared for a forest, a shallow pond, and an "old field."

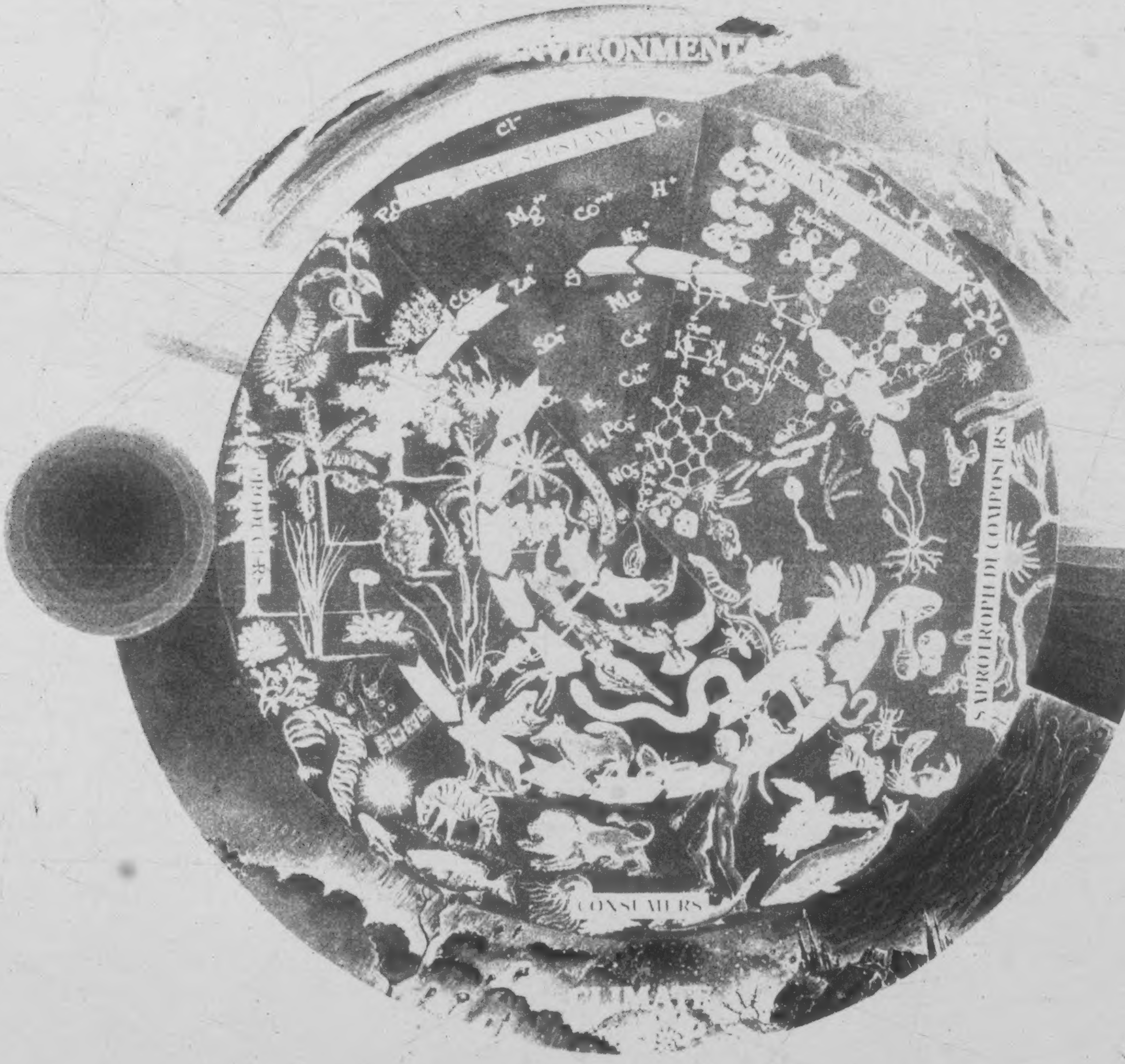
The numbers pyramid is probably the least meaningful. Knowing, for example, the tremendous numbers of daphina (water fleas) required to support one fish provides a dramatic picture; but this method is of little use in comparing the pond to a different ecosystem because all individuals are treated equally, regardless of size. It is difficult to compare numbers of algal cells (pond) to grass plants (old field) or to trees (forest) (fig. 15).

A somewhat better comparison can be made with a biomass pyramid. This pyramid provides a rough picture of the food chain relationships for the entire ecosystem, especially when the sizes of the organisms in successive trophic levels are similar. But Consumers may outweigh the Producers; in lakes and oceans in winter, for example, small, short-lived phytoplankton Producers may be outweighed by the larger, longer-lived zooplankton Consumers. So the biomass pyramid of the ocean, like the numbers pyramid of the forest, may be inverted.

The energy pyramid provides the best overview of trophic level relationships. These pyramids show the rates at which food energy passes through the food chain and allow comparisons of the same trophic levels of different ecosystems and of the relative importance of individual groups within a trophic level. In our example in figure 15, the amounts of food energy available for the next trophic levels in the three ecosystems are of the same "scale." These pyramids will always be right side up because of the Second Energy Rule.

61

Figure 16. — *The cyclic flow of nutrients within an ecosystem. The arrows show the paths of nutrient flow between the living and non-living players.*



ENVIRONMENT
INORGANIC SUBSTANCES
ORGANIC SUBSTANCES
PRODUCERS
SAPROTROPHIC DECOMPOSERS
CONSUMERS
CLIMATE
Cl⁻
Mg++
Co++
H+
Mn++
Ca++
NO3⁻

MATERIAL CYCLING RULES OF THE GAME

We stated earlier that biogeochemistry is the study of the exchange of materials between the living and nonliving Players. Biogeochemical cycles show the pathways for the circulation of nutrients essential for life (from environment to organisms to environment). The movement of nutrients through an ecosystem occurs as energy is transformed from one state to another, but unlike energy, whose flow is one way, the flow of nutrients is cyclic (fig. 16).

The cycling of nutrients is made possible by the Saprotroph Players, the *macroconsumers* and *microconsumers* that break down dead tissues of Producers and Consumers. Thus essential elements for growth such as nitrogen, phosphorus, sulfur, carbon, and calcium from the decomposition process are absorbed and used by the green plants, by Consumers at several trophic levels, and again by the plants.

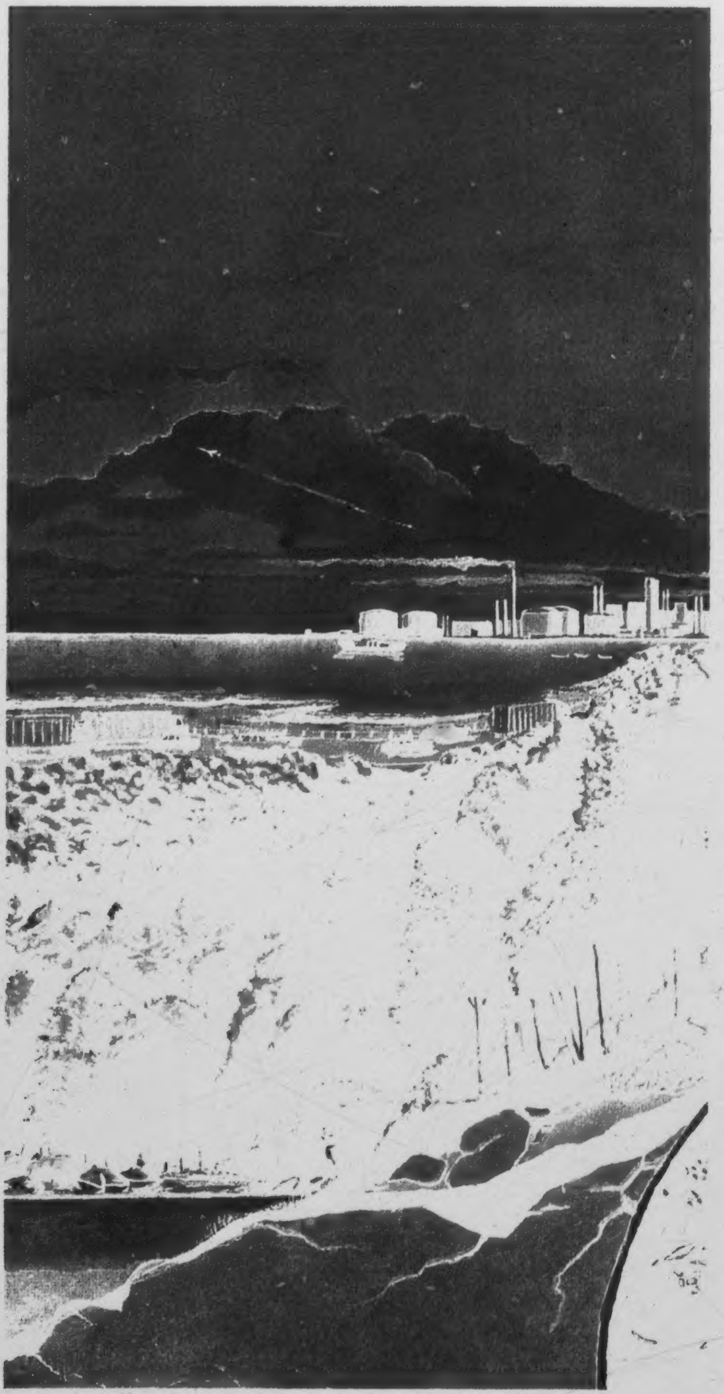
Cycle pools

Each nutrient cycle has two compartments or "pools." The *reservoir pool,* the largest, can be immediately unavailable to Players because of its location or the chemical form of the nutrient. The smaller *active pool* is available to organisms and is cycled or exchanged between them and their immediate environment.

Types of cycles

When the reservoir pool is located in the earth's crust, the nutrient cycle is termed *sedimentary.* When this pool is in the atmosphere or hydrosphere, the nutrient cycle is a *gaseous* one.

The biogeochemical cycles in figures 17 through 28 are examples of how water and a few of life's essential nutrients move within ecosystems. It should be recognized that there also are cycles of many materials that are *harmful* to life. The effects of some of these latter cycles are discussed on pages 127 through 137.



An Arena for some Biogeochemical Cycles

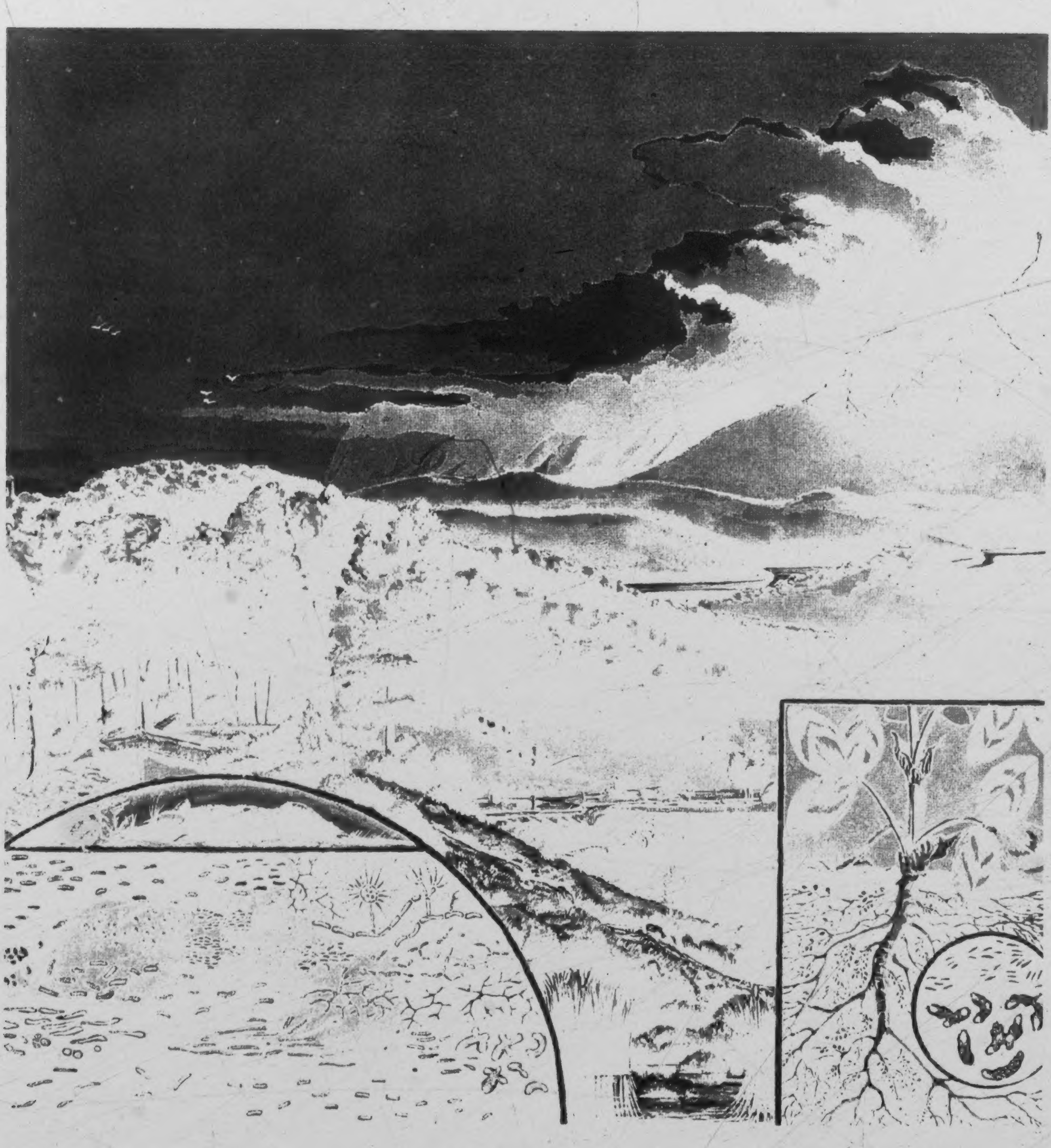
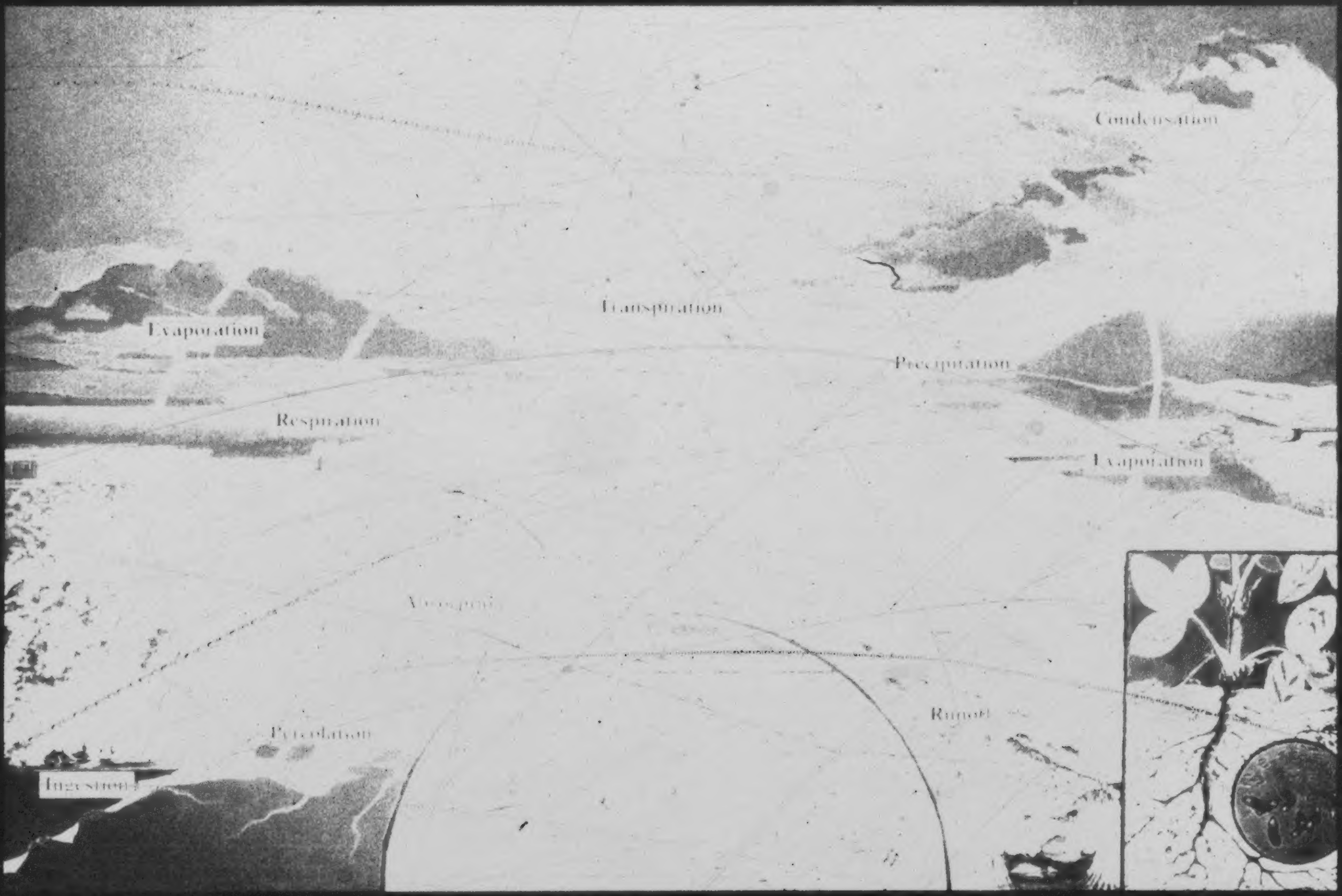


Figure 17. — *The primary pathways and processes of the water cycle. Passive movements of liquid water (condensation, precipitation, percolation, and overground transport) are shown by green arrows, active uptake by plants and animals (absorption and ingestion) are shown by red arrows, and the return to the atmosphere (evaporation, transpiration, and respiration) are shown with blue arrows.*


Condensation
Transpiration
Evaporation
Precipitation
Respiration
Evaporation
Absorption
Runoff
Percolation
Ingestion

66

SOME IMPORTANT BIOGEOCHEMICAL CYCLES

The water cycle

Water is by far the most abundant and most important single substance in the biosphere. Fresh water is present as water vapor in the atmosphere; as a liquid in the atmosphere, on land, and in water bodies; and as solid ice in the polar caps and glaciers. But about 97 percent of all water is the liquid salt water of the oceans and seas.

Water is a major geological force. Fracturing and pulverizing rock by its unique property of expanding upon freezing, water erodes and transports sediments and dissolved substances from high elevations to low ones, from one location to another. It is the primary force in leveling mountains and in filling valleys and lowlands. Because water stores heat energy better than any other liquid, it can transport heat energy great distances. Examples of this important characteristic include transporting heat across the Atlantic by the Gulf Stream current and the use of water to carry heat from nuclear reactors. This same property is a powerful factor in regulating climate—especially near coastal areas.

Water is the medium of all life processes. It transports nutrients as it flows through soil and through living matter. Water also removes and dilutes many natural and artificial wastes.

Like all biogeochemical cycles, the water cycle (fig. 17) is powered by energy from the sun. Water vapor enters the atmosphere through *evaporation* from bodies of water and from soil and through *transpiration* from the leaves of vegetation. This water vapor in the cool reaches of the atmosphere condenses to form clouds *(condensation)*. When water droplets become heavy, they leave the atmosphere and return to earth as rain or snow *(precipitation)*.

Some of the water falling on land flows over the surface to streams and other bodies of water; some percolates into the ground where it can also flow underground to a water body *(percolation)*; and some is absorbed by plant roots *(absorption)*. Animals obtain water directly by drinking it *(ingestion)* or indirectly by eating green plants. Water transports wastes from living tissues; it leaves animals as urine, perspiration, and as exhaled water vapor *(respiration)*. All organisms lose the water in their tissue when they die and decompose (*decomposition*).

IN YOUR ENVIRONMENTAL ARENA

- ☐ Draw a diagram showing how you fit into the water cycle.
- ☐ List the sources of water in your community.
- ☐ How is water used in your community?
- ☐ Is the water treated before it can be used? If so, how? Why is it treated?
- ☐ What can you do to help conserve water?

The carbon cycle

We usually think of the carbon cycle (fig. 18), one of the most important to man, as the carbon dioxide cycle because most of the carbon is available as carbon dioxide in the atmosphere, as dissolved carbon dioxide in oceans, or as "stored" carbonates. Excess carbon dioxide in the atmosphere dissolves in the oceans and atmospheric deficits are replaced by carbon dioxide from the oceans. Thus the oceans partially regulate this cycle (fig. 18, blue arrow).

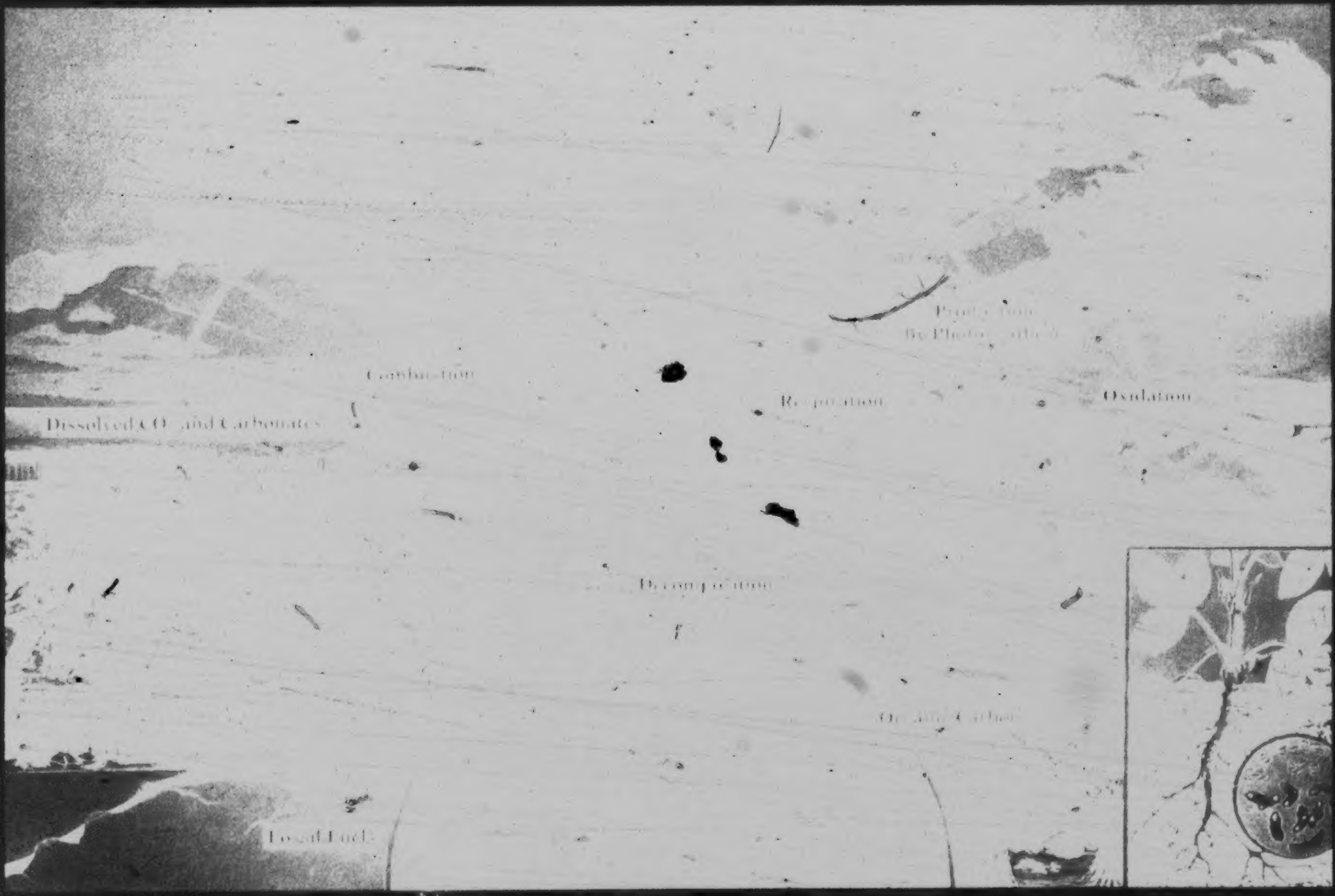
Green plants use carbon dioxide from air or water to make carbohydrates and fats *(production* by *photosynthesis)* as was mentioned on page 40. These energy-rich compounds are passed on to Consumers who cannot synthesize their own Organic Compounds directly from carbon dioxide and water. As plants and animals respire *(respiration)* and, finally, when their bodies decompose *(decomposition),* carbon dioxide is returned to the atmosphere. When production exceeds decomposition, organic matter accumulates and becomes incorporated in the earth's crust.

Today, people are materially affecting the carbon cycle by their activities that require the tremendous *combustion* of fossil fuels and the increased *oxidation* of organic matter in soil through agriculture and the draining of wetlands. Each year, these activities inject into the atmosphere billions of tons of carbon dioxide.

Over the last half century, the carbon dioxide content in the atmosphere has increased by about 13 percent; it has been predicted that atmospheric carbon dioxide will increase by an additional 25 percent by the year 2000. These increases may significantly affect our global climate.

In the processes shown in figure 18, carbon is always associated with oxygen, so the carbon cycle also can be considered an oxygen cycle. Oxygen produced during *photosynthesis* is consumed by animals and plants in *respiration* and it is used in the processes of *decomposition, combustion,* and *oxidation.*

Figure 18. — *The carbon cycle, one of the most important to man, is also known as the carbon dioxide cycle. It can also be considered an oxygen cycle. In this illustration, the biological fixing of carbon dioxide by green plants (photosynthesis) and the transfer of organic carbon to Consumers is shown by green arrows; the return of carbon to the atmosphere (combustion, oxidation, decomposition, respiration) is shown in red. The passive transfer of carbon dioxide between atmosphere and oceans is shown in blue.*


Production
By Photosynthesis
Combustion
Respiration
Oxidation
Dissolved CO2 and Carbonates
Decomposition
Organic Carbon
Fossil Fuels

The nitrogen cycle

Nitrogen is a particularly important element for the health and well-being of people. Proteins, nucleic acids, vitamins, hormones, and enzymes that contain nitrogen are required for many essential bodily functions. Although nitrogen makes up 79 percent of the atmosphere that bathes the earth, our food supply depends more on the availability of this element in a usable form than that of any other. The nitrogen cycle (fig. 19) is complex; it includes the activities of many groups of microbes. It is a marvelous example of how important microbes are to life itself.

To be used by green plants, gaseous nitrogen (N_2) must be converted or *fixed* into usable compounds by electrification (lightning), by industrial processes, or by nitrogen-fixing bacteria and algae. Nitrogen-fixing organisms in soil, water, and especially those in nodules on the roots of legumes convert gaseous nitrogen into highly soluble salts of nitrates (NO_3^-) and ammonium (NH_4^+) (fig. 19, step 4). Plants absorb these compounds and convert them into nucleic acids and amino acids and eventually into proteins. Animals obtain nitrogen as plant-produced amino acids ($-NH_2$); they use these acids to build protein and other molecules.

Figures 19, 50, and 52 also show some of the ways that people influence the nitrogen cycle. Internal combustion engines emit nitrous oxides; huge quantities of nitrate and ammonium salts are produced and applied as fertilizers; tremendous amounts of nitrates are concentrated in animal and human wastes; and human activities result in increased erosion and runoff of nitrates into streams, lakes, and rivers.

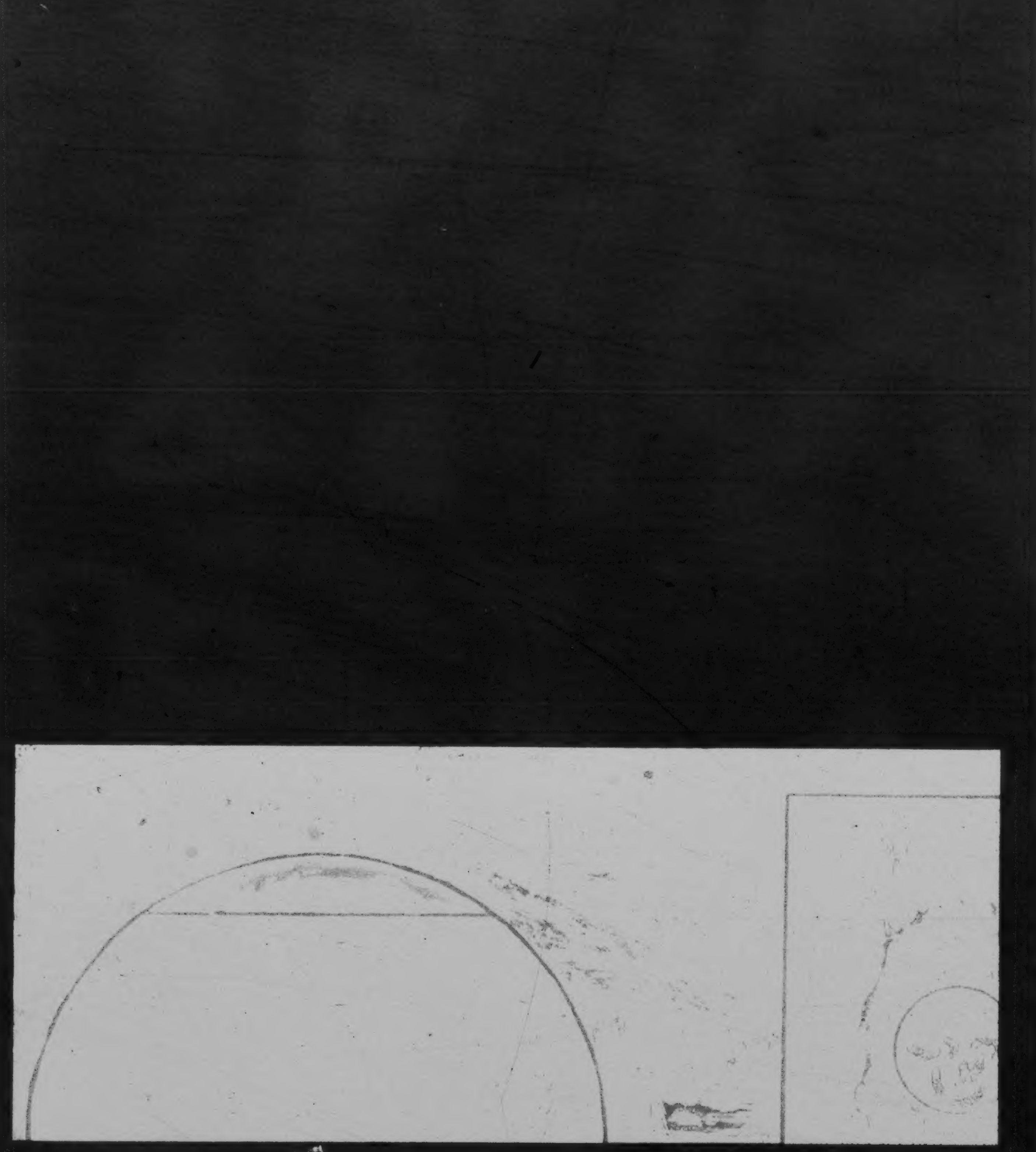
The nitrogen cycle continues as protein from dead animals and plants is converted by decomposer organisms back into ammonium salts and ammonia gas (NH_3) (fig. 19, steps 1 and 3); this cycle is completed by other groups of bacteria that convert these compounds into nitrite ions (NO_2^-) or into atmospheric nitrogen (fig. 19, steps 2 and 5).

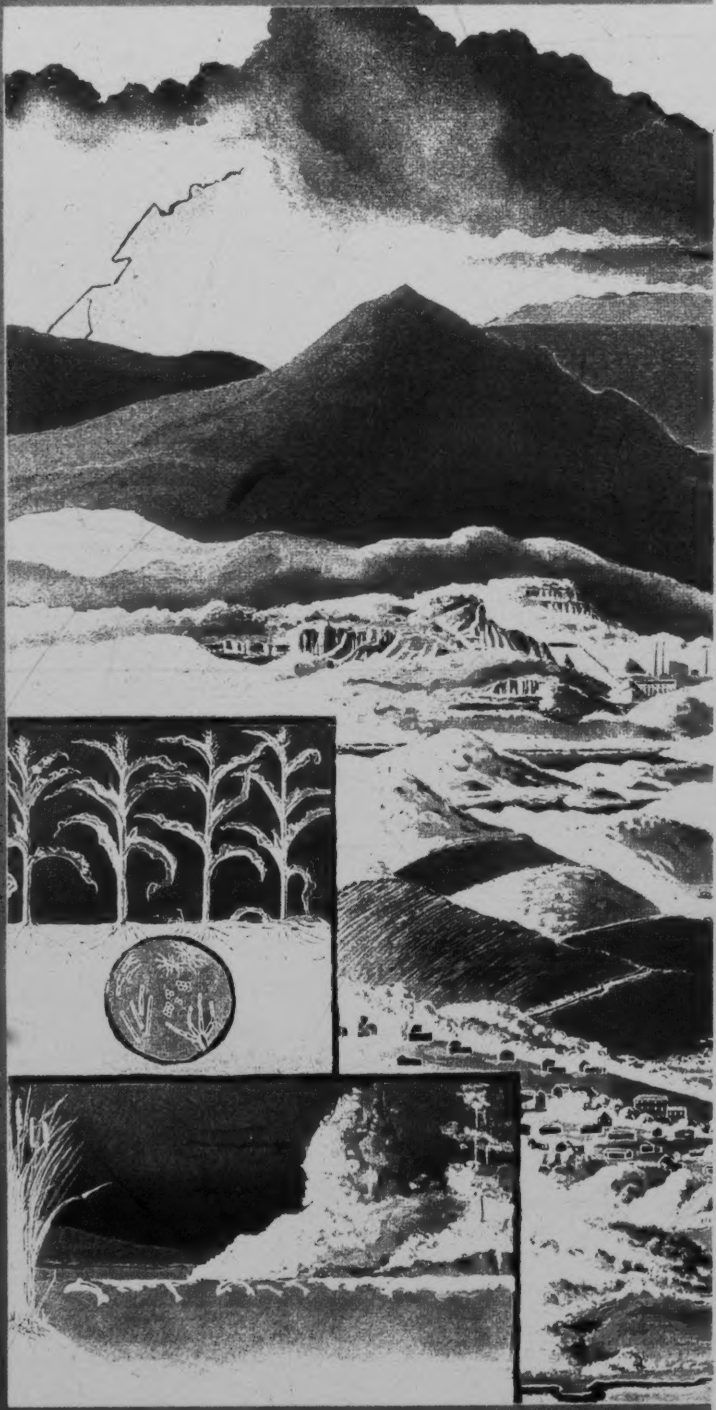
Figure 19. — *The complex nitrogen cycle is a marvelous example of how microbes are important to life itself (parts of cycle illustrated by red or green arrows); this cycle also includes abiotic processes (blue arrows).*

This complicated cycle also includes bacteria that can reconvert the nitrite ions to nitrate ions for use by plants (fig. 19, step 2). Some nitrogen is lost from the cycle when dissolved nitrates are leached (washed out of soil) into streams, rivers, and finally into the deep sediments of the seas; this loss is probably balanced by the nitrogen that reenters the air in volcanic gases.

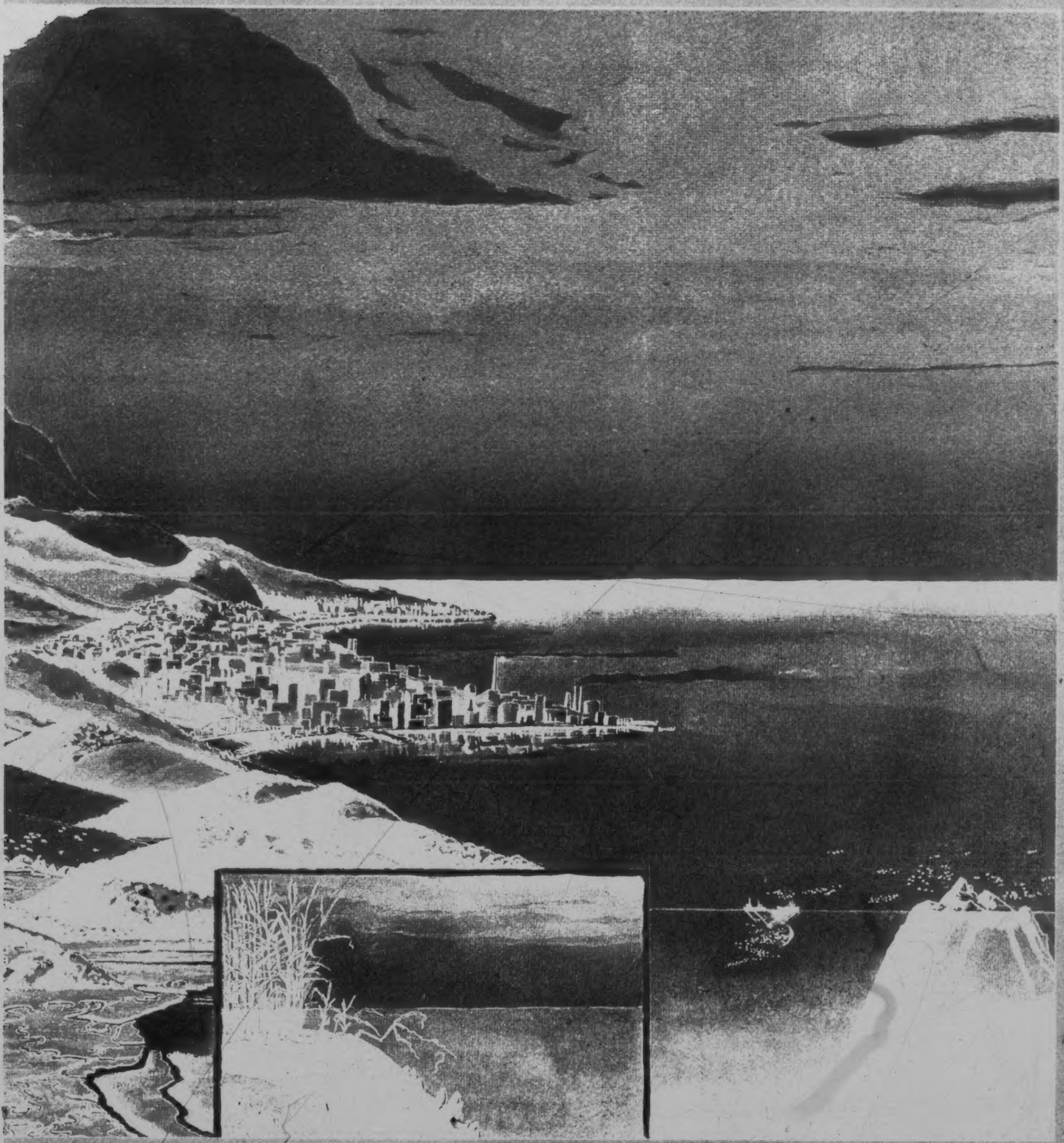
The microbes and higher organisms that convert nitrates to proteins acquire their energy from other organic matter or from the sun (fig. 19, green arrows), while those specialized groups of bacteria that reconvert proteins to nitrates derive their energy from the chemical degradation process itself (fig. 19, red arrows). The inserts in figure 20 illustrate the major microbial forms involved in the five steps of the nitrogen cycle.

Figure 20.—*Some representatives of the many groups of microorganisms, primarily bacteria, that are involved in the five steps of the nitrogen cycle.*





The Landscape of the Phosphorus Cycle



The phosphorus cycle

Phosphorus is an element of major significance; it is a necessary component of the protoplasm of every living cell. As part of adenosine triphosphate (ATP), phosphorus plays a key role in the storage and supply of energy, and it is an important component of the nucleic acids DNA and RNA. Phosphorus is also a major component of bones and teeth.

The cycling of phosphorus through several ecosystems is shown in figure 21. This is a sedimentary cycle—the reservoir pool is in rocks, in deposits of fossilized bone formed in past geological ages, or in great beds of sea bird excreta, or guano, on islands near Peru.

The weathering of these deposits, sometimes hastened by mining, releases phosphates—usually inorganic orthophosphate compounds (PO_4)—into soil or aquatic ecosystems where they can be absorbed by the green plant Producers and used in synthesizing protoplasm. Herbivore Consumers obtain much of this phosphorus when they eat plants. When plants and animals die, the decomposer Consumers return the phosphorus to soil or water as dissolved Organic Compounds. Excreta from animals, including people, contribute organic matter rich in phosphorus to soil and water systems. Bacteria then break down these Organic Compounds into inorganic phosphates that reenter the cycle.

Figure 21. — *The paths along which phosphorus moves through ecosystems from rock and guano deposits to the sea (red arrows) and back to land again (blue arrows). Along the way, phosphorus is cycled between the living and nonliving Players (green arrows).*

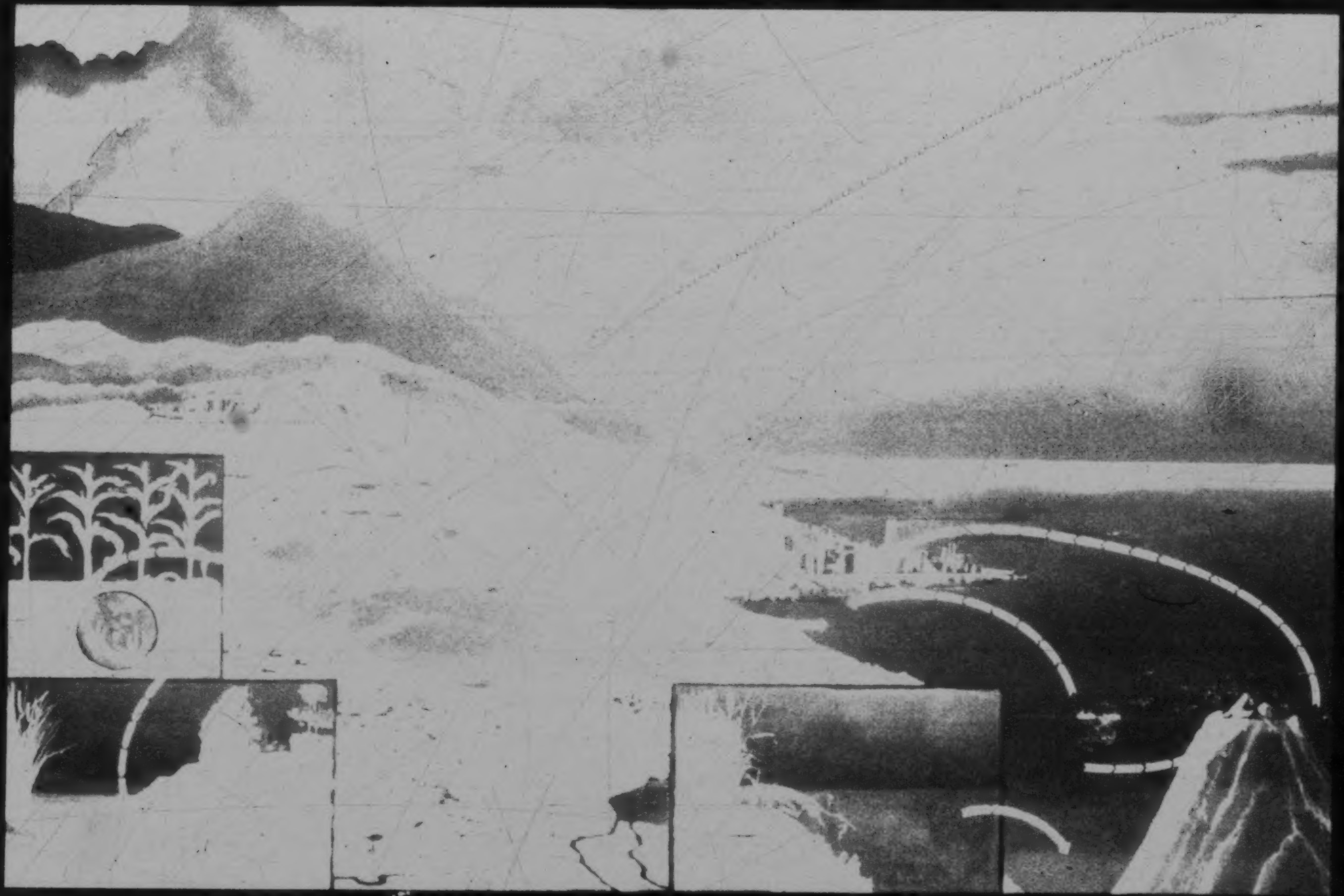
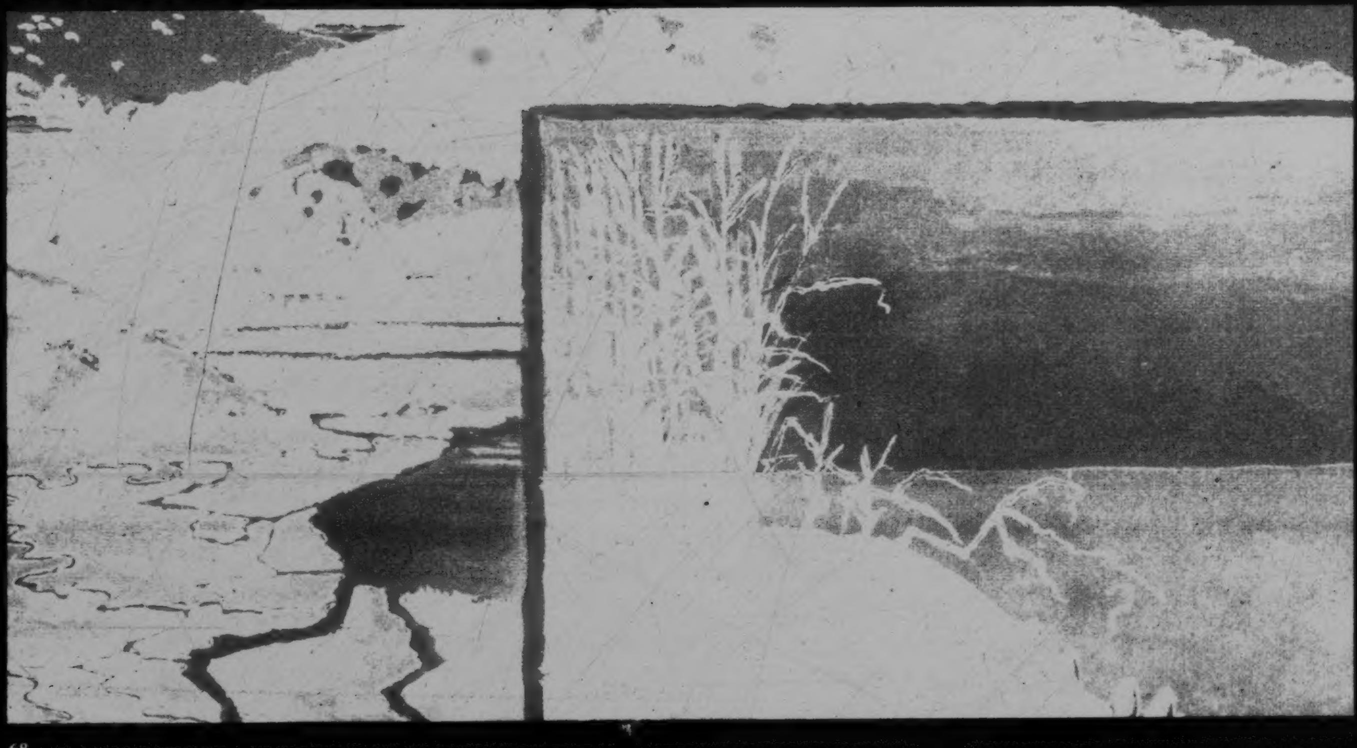


Figure 22. — *Eutrophication or aging is speeded up when too much phosphorus "leaks" into fresh water bodies.*

Figure 23. — *Phosphorus cycles rapidly between water, sediments, and shellfish in the salt marsh ecosystem.*



Considerable quantities of phosphorus "leak" into waterways and eventually are deposited in shallow marine sediments. Along the way, excessive amounts of dissolved phosphates from sewage treatment systems and from farm feedlots can cause "traffic jams" of phosphorus. An excess of phosphorus in water causes an increase in plant life and an increase in the natural process of aging in ponds or lakes, call *eutrophication* (fig. 22).

Upon reaching the shallow salt marsh estuary ecosystems, phosphates are cycled rapidly between the sediment reservoir and the detritus reservoir (fig. 23, insert). Phosphorus absorbed from deep marsh sediments by the marsh grass Producers is released from the dead grass detritus (see page 29 for a discussion of detritus) by Consumer detritus feeders (for example, fiddler crabs), is absorbed and accumulated by Consumer filter-feeding organisms (ribbed mussels), and is released again to the water and sediments for recycling by the grasses. These estuary systems are the repository of most soil and other matter removed from the land and carried in streams. They act as "nutrient traps" and are very sensitive to the pollution that often arises from activities far away.

Figure 24. — *Large quantities of phosphorus are flushed down rivers and reach the sea.*

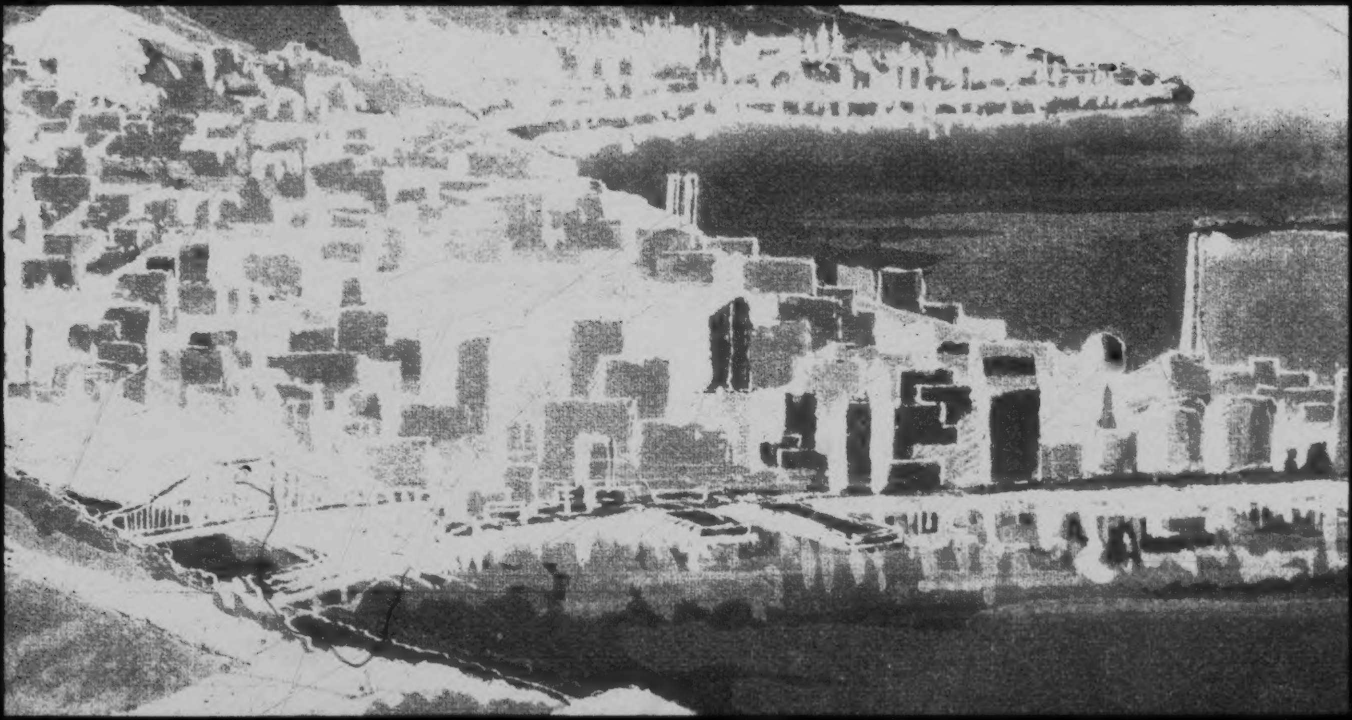
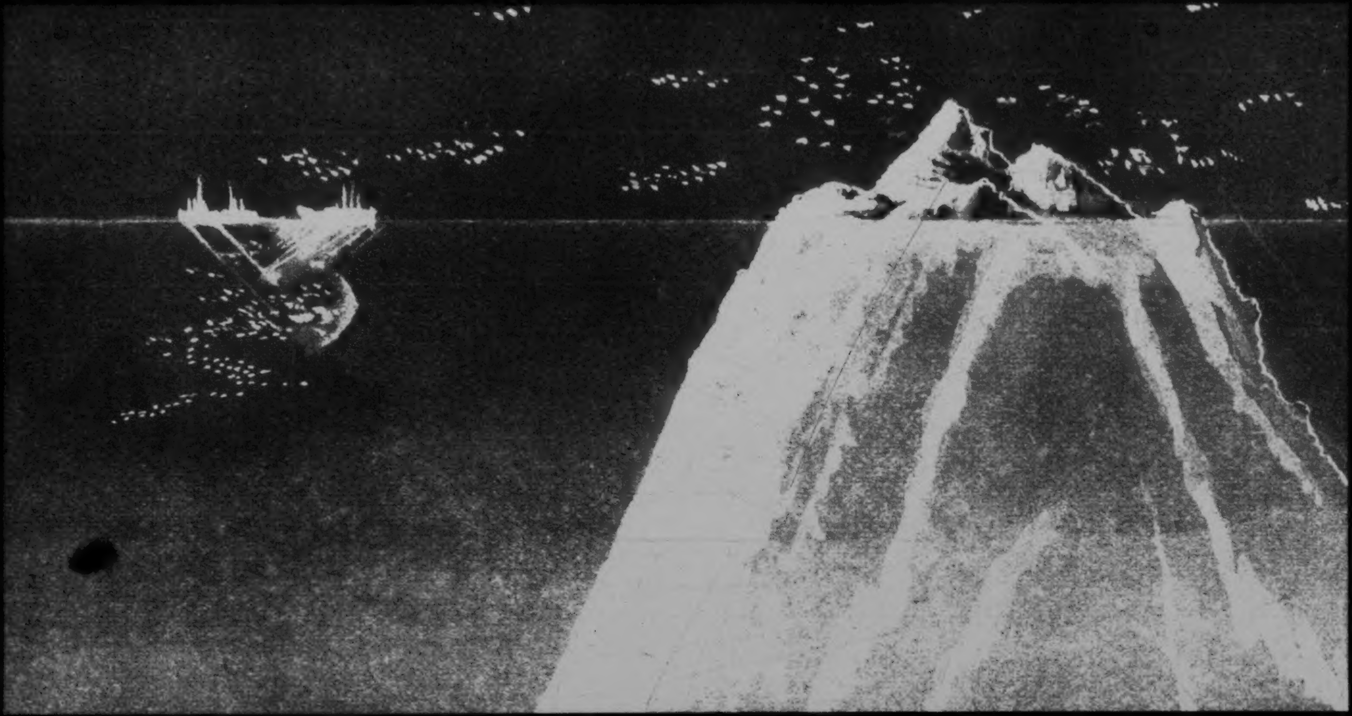


Figure 25. — *The large amounts of phosphorus returned to the land by fishing or by birds is far exceeded by losses to deep marine sediments.*



Large quantities of phosphorus are lost from the "nutrient trap" estuary arena or are deposited more directly by rivers to the open waters of the oceans (fig. 24). Here, phosphorus may be cycled by phytoplankton Producers through several food levels or it may be "lost" to the deep marine sediments.

Large amounts of this nutrient are returned to land each year by fishing activities or are deposited on islands as guano of fish-eating birds (fig. 25). But the losses to deep sediments each year exceed by many thousands of tons the amounts that are returned to land.

A Forest Watershed in New England: A Laboratory for Studying Nutrient Cycles

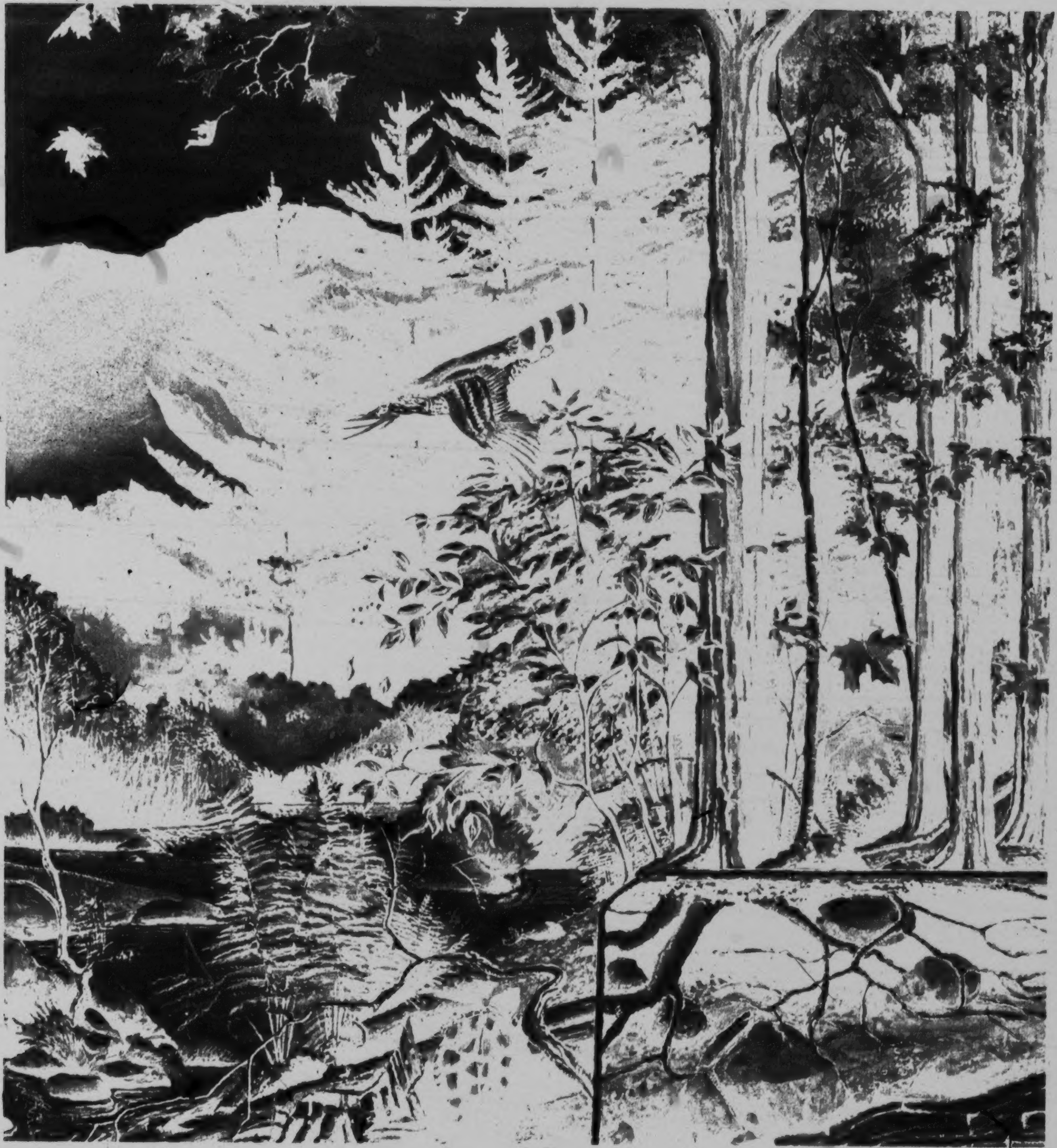


Figure 26. — *The calcium flowing out of a New England watershed (blue arrow) was balanced by that entering this ecosystem through rainfall and through weathering of parent bedrock (red arrows). The figures are given in kilograms per hectare per year. The green arrows show the amount exchanged each year between soil and plants.*

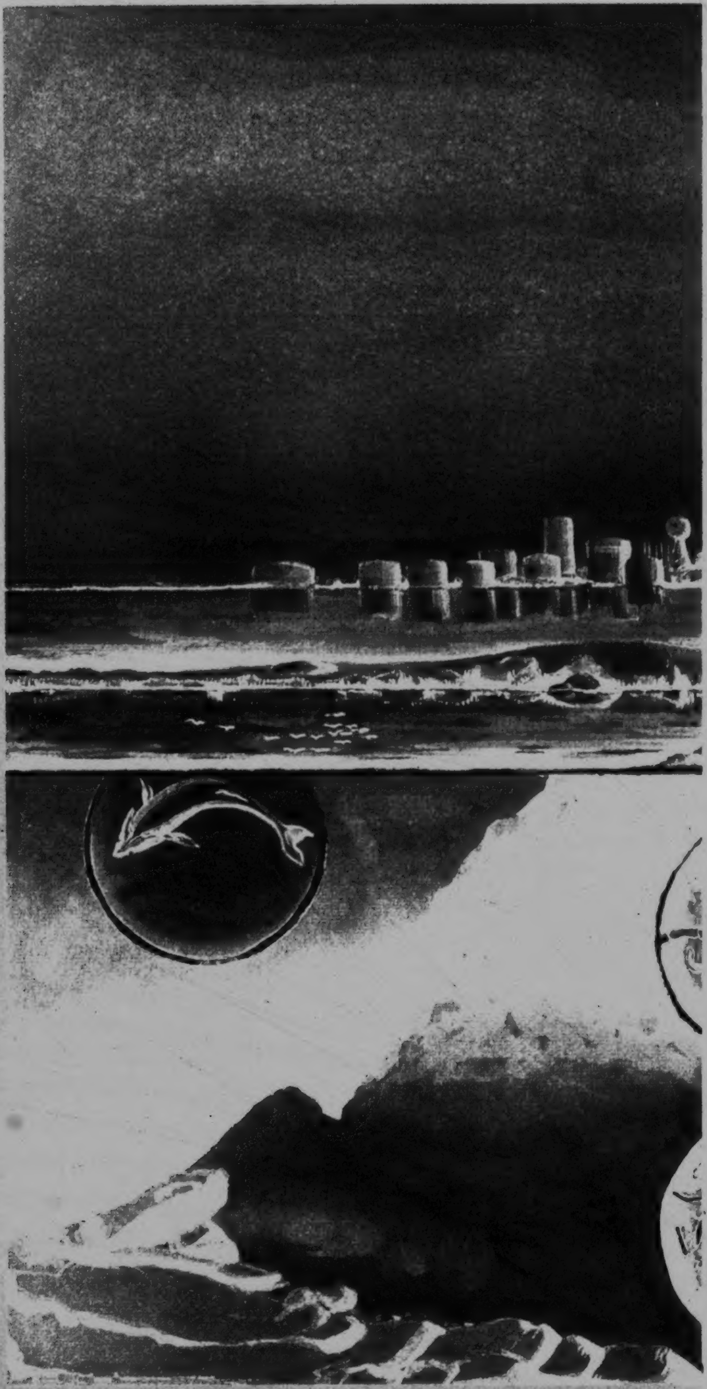
The concentration of elements in an ecosystem at a given point in time gives only a limited view of their importance. The study of the "turnover" and distribution of nutrients—of the fate and whereabouts of essential materials—can greatly help our understanding of what is going on around us. This is illustrated in the following discussion of the calcium cycle.

The calcium cycle

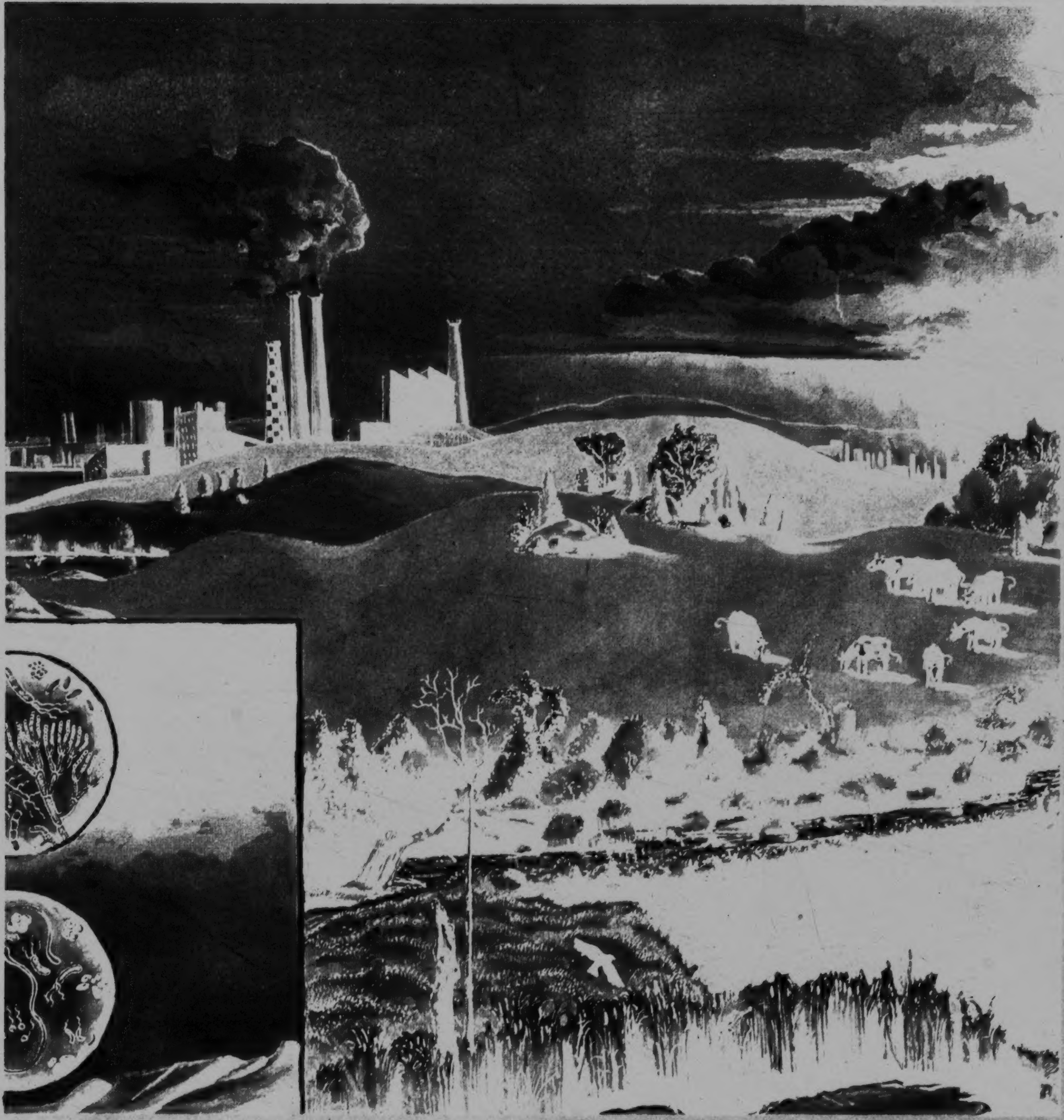
Calcium is another element of vital importance. In plants it is a major component, as *calcium pectate*, of a thin layer that "cements" cell walls together; in animals, calcium is the primary component of bones, teeth, and shells. The large nonliving reservoir of calcium is located in the rock sediments.

The rates of exchange of calcium between the nonliving and the smaller living reservoirs were determined for some northern New England watersheds (a watershed includes the stream and all the land over and through which water drains into the stream). Figure 26 shows that the cycling of calcium was so "tight" in this forest watershed that only about 8 kilograms (kg) of calcium per hectare (ha) (about 7 lb/acre) left the ecosystem annually by means of the stream. Since 3 kilograms per hectare of calcium (2.67 lb/acre) entered the watershed in precipitation each year, the amount needed to "balance" the loss, 5 kilograms (4.5 lb), was obtained from weathering of the rock reservoir.

The active flux of 50 kilograms per hectare (about 45 lb/acre) per year between the soil and plants is made possible by trees and shrubs, such as sugar maples and dogwoods, that remove calcium from deep layers with their roots and deposit their calcium-rich leaves on the upper soil layers. When streamflow was increased by cutting vegetation and suppressing the regrowth in a portion of the watershed, the tight nutrient cycle was greatly modified. Losses of mineral nutrients in streamflow, including calcium, increased 3 to 15 times.



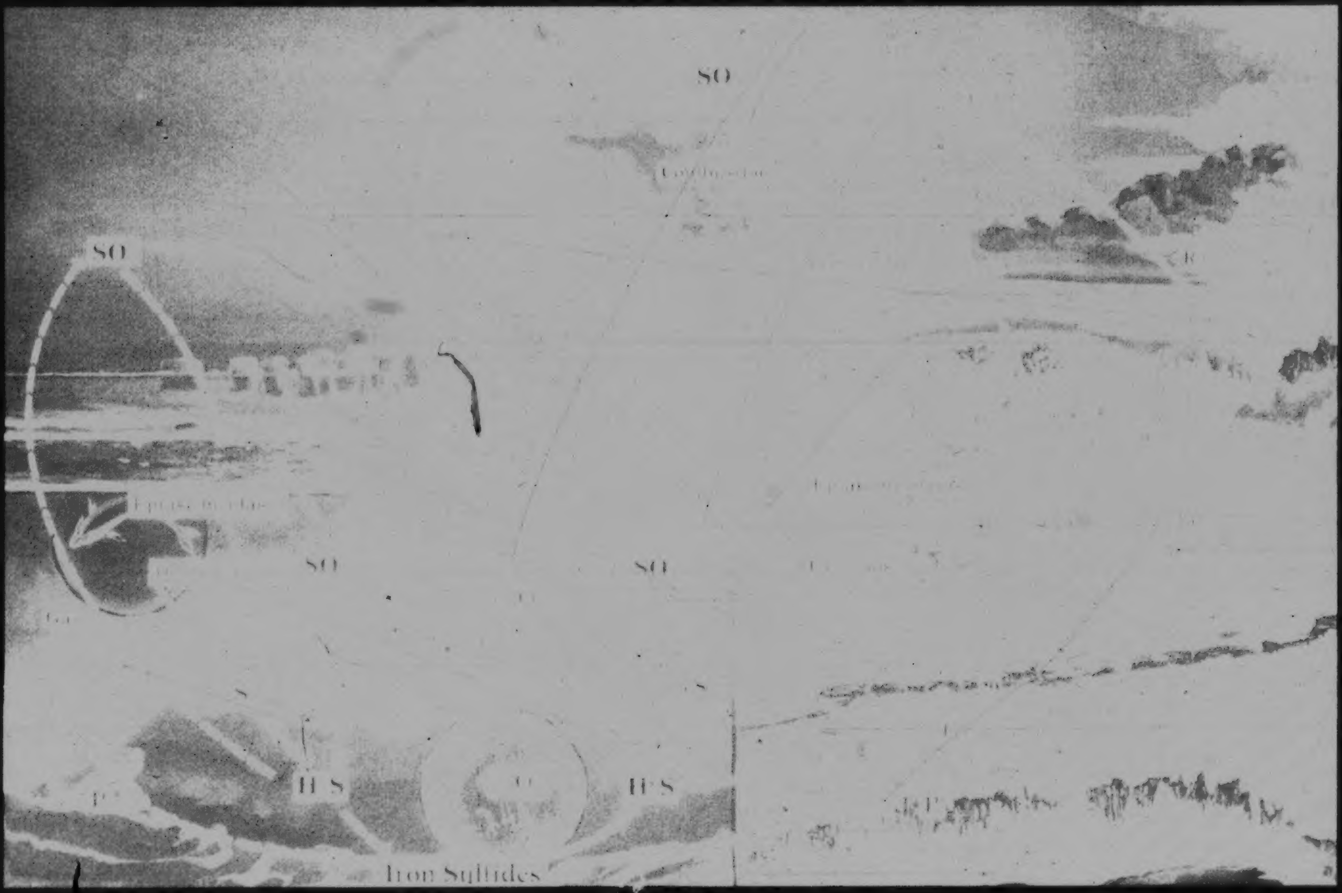
A Setting for the Sulfur Cycle



The sulfur cycle

Sulfur, an essential component of certain amino acids, is incorporated as sulfates into proteins by the green plant Producers. Its cycle is a good example of one that bridges air, soil, and water (fig. 27). It includes both a sedimentary pool and a smaller atmospheric pool; and it illustrates again the importance of microorganisms in converting an element from one form to another. The sulfur cycle also directly affects the phosphorus cycle because phosphorus is made available to plants when iron sulfides are formed in sediments.

Figure 27.—*As sulfur cycles through the biosphere, it occurs in many forms.*

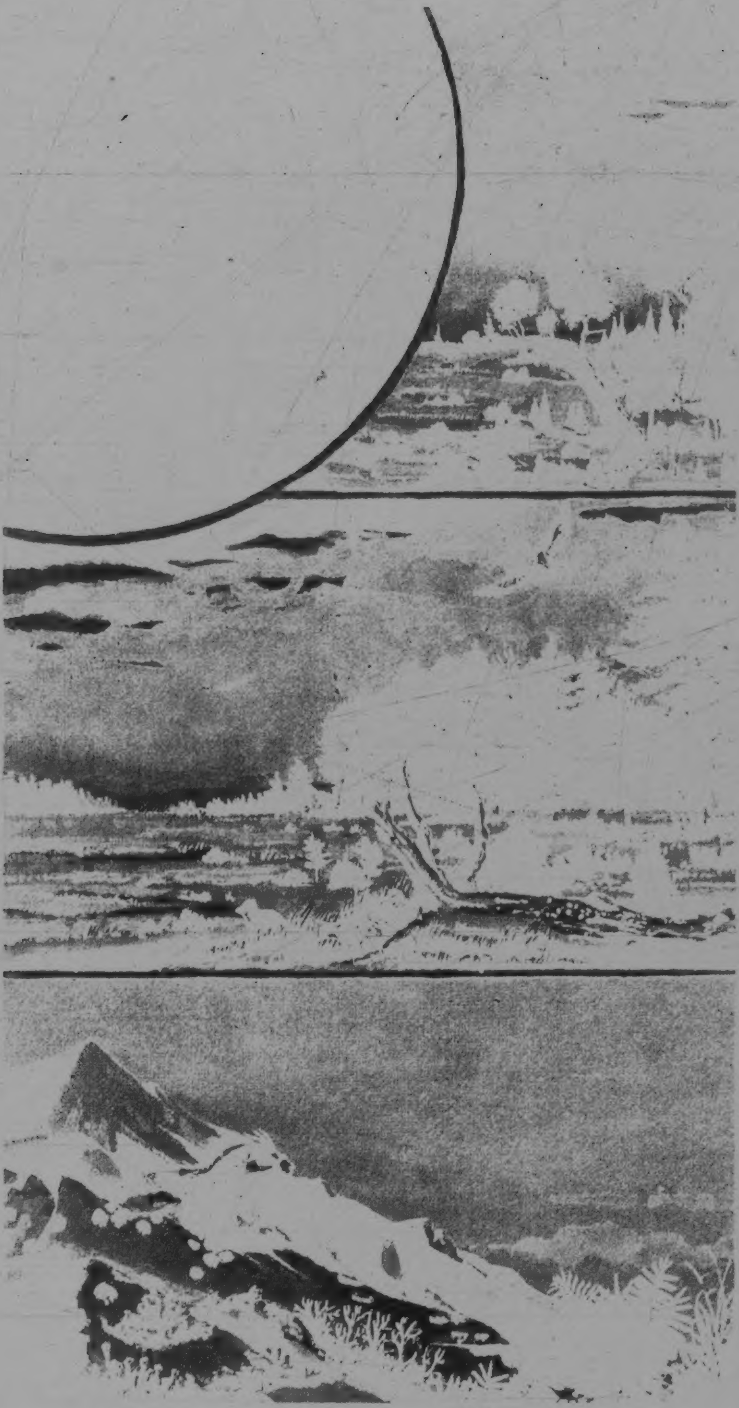


The microorganisms in figure 28 are representative of those that convert one form of sulfur to another. Those in the shallow sediment (upper circle) are aerobes (operating in the presence of and adding oxygen), while those in the deeper sediment (lower circle) are responsible for anaerobic reductions (removing oxygen). Some of these anaerobes are especially important because they reduce sulfates (SO_4) to hydrogen sulfide gas (H_2) which, as it moves upward, makes sulfur available to other organisms in the shallower sediments of the ecosystem.

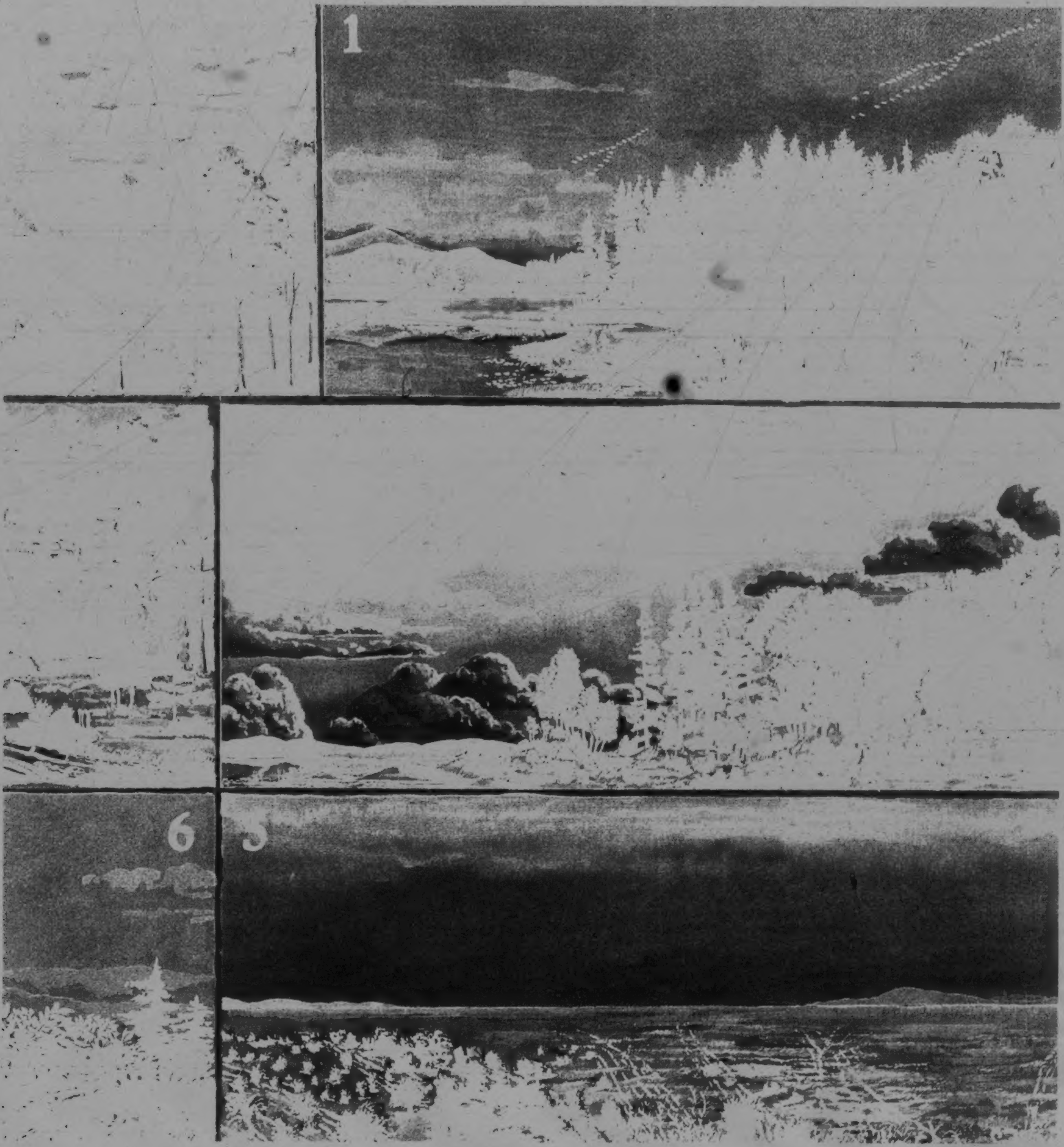
The sulfur cycle is becoming increasingly important because it is being affected adversely by human action. The burning of fossil fuels that contain sulfur has caused a dramatic increase in the amount of sulfur dioxide (SO_2) in the atmosphere in some areas (see page 131).

Figure 28. — *Fungi and bacteria of the sulfur cycle: aerobes in the upper circle, anaerobes in lower circle.*

IV. CHANGING PLAYERS AND PLAYING FIELDS: ECOLOGICAL SUCCESSION



Each of the drawings shows (from left to right) an ecosystem's change over time. The changes illustrate how some ecologists believe succession has proceeded in some specific situations. More details are given on the following pages. In most cases there are other successional pathways. Indeed, it is unlikely that any two locations [illegible] in the rate or the type of their major developments.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We discovered earlier that all ecosystems are governed by the same rules of energy flow and material cycling and that each ecosystem contains Players in the Game of the Environment with roles parallel to those in the other ecosystems. When ecosystems are left to their own devices to follow the Rules of the Game, each will continue to change—to develop and mature—in a relatively orderly and predictable way. This process of change over time, called *succession* or *biotic development*, results when the living Players, especially plants, interact with and modify their environment. Plants modify their environment in very complex ways; this modification can be physical or chemical, and plants present at one point in time even can render a Playing Field unsuitable for themselves and more favorable for other plants that eventually may replace them.

The pace of succession varies greatly. Where environmental factors are favorable and when seeds of plants of later stages are available, succession proceeds rapidly until plants and their environment are essentially in equilibrium—then further change is very slow. This relatively "stable" situation is sometimes called the successional climax. When moisture or nutrients are limited by geology, topography, or climate, succession may be imperceptible—it may even be held in check.

SOME EXAMPLES OF SUCCESSION

Northern pond

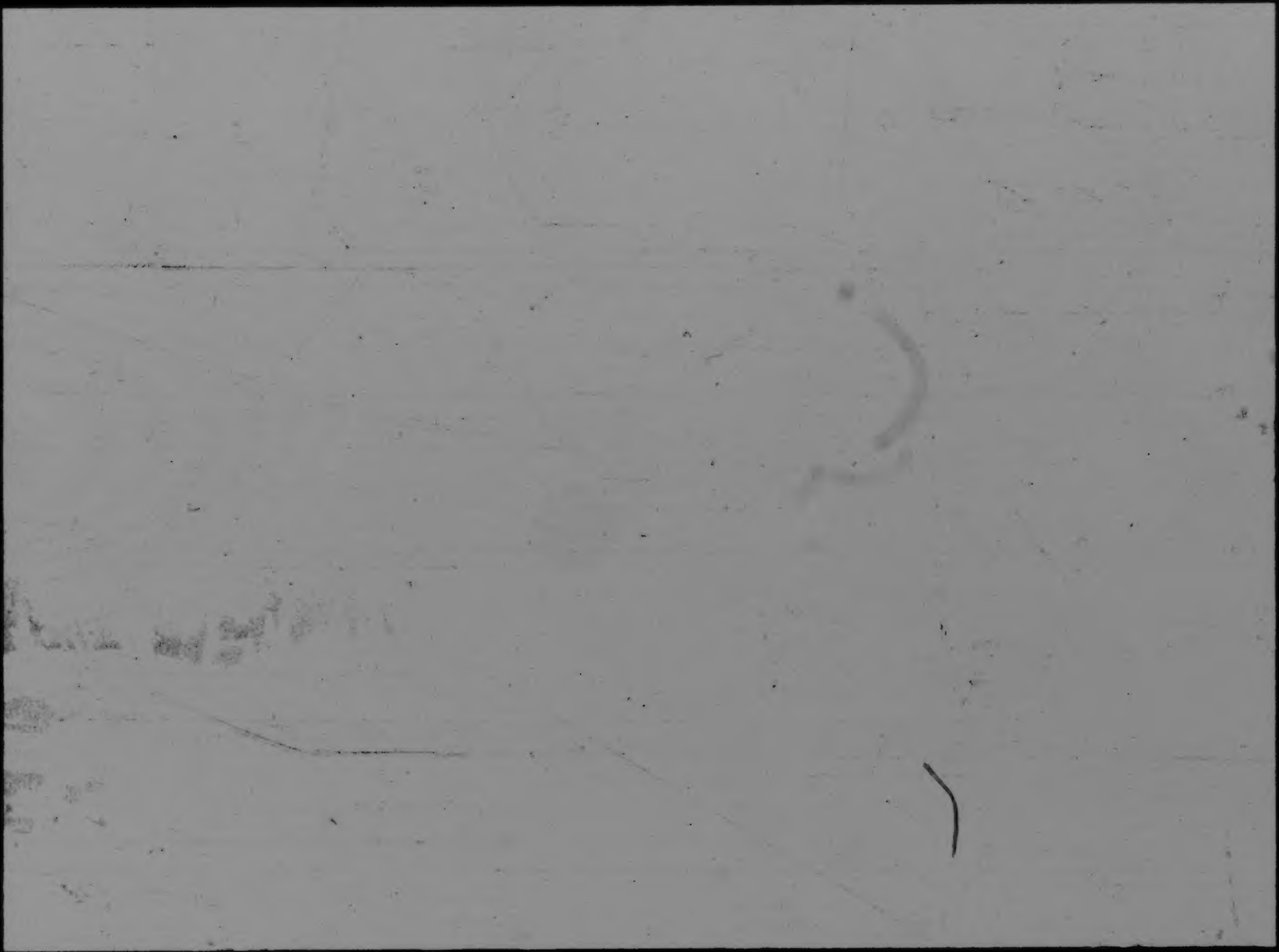
The northern boreal pond in figure 29 is slowly evolving into a bog, and it may eventually be a northern swamp forest of red maple, spruce, fir, and larch. In some cases, it is even possible for succession to continue until an upland forest with birch and maple develops. Vegetation in the pond begins as pioneer sedges colonize the water's edge and sphagnum moss develops into a floating mat along the shoreline. As the moss grows, dies, and collects organic debris, a few forbs begin to grow on it and in it, adding to the nutrient base. Later, trees such as larch, red maple, and black spruce grow, the pond fills in, and the pond becomes a sphagnum bog. As organic matter continues to accumulate and the bog dries, the trees develop further and the bog becomes a swamp forest.

Figure 29. — *Succession causes a northern pond* (left) *to change into a sphagnum bog* (center foreground). *The bog may then become a relatively stable swamp forest of red maple, spruce, fir, and larch* (center background). *A forest of northern hardwood trees may eventually develop here.*

Old field

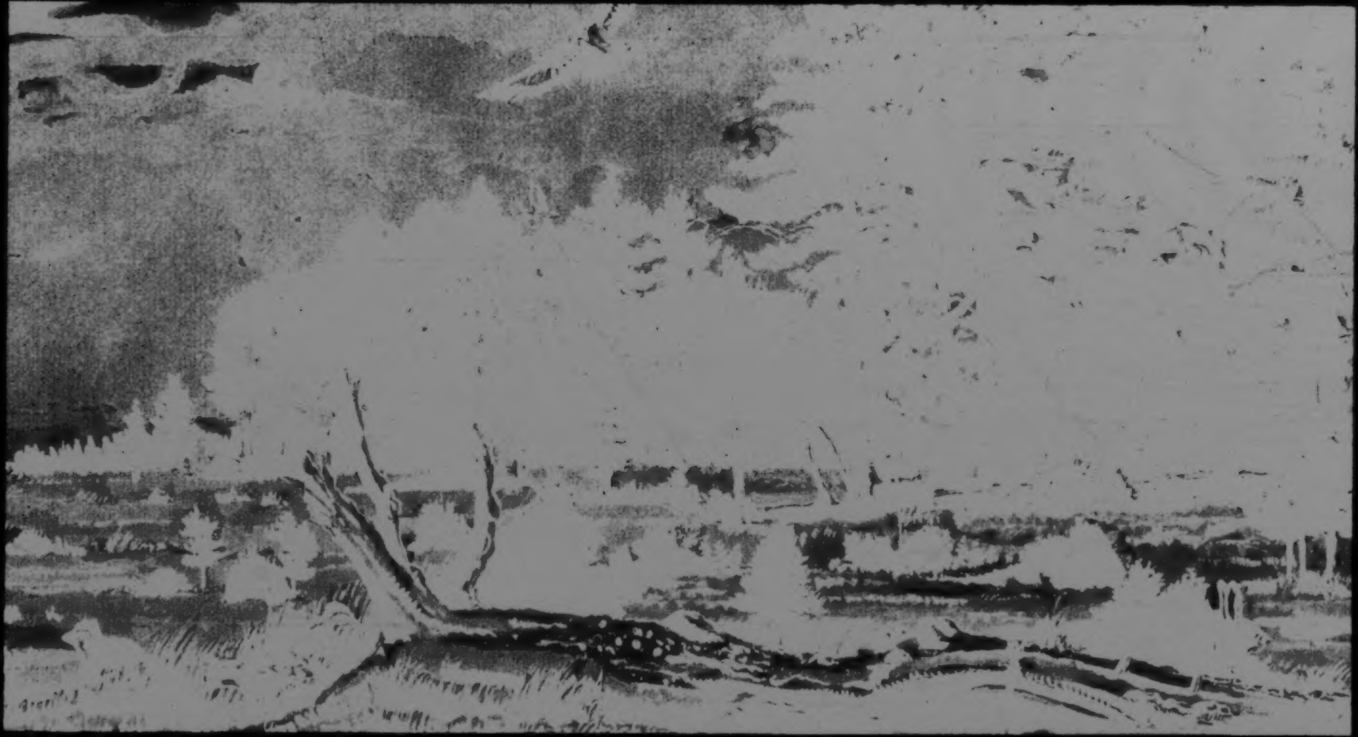
Classic old field development or succession in New England is shown in figure 30. Abandoned farmlands are invaded by pioneer grasses and forbs, and by woody species such as redcedar and black cherry. Tree species such as oaks, which may make their appearance early, usually become dominant later. These species then may give way, especially on moist, cool sites in northern New England, to the more shade tolerant species—sugar maple, yellow birch, and American beech. Successional development from a plowed field to a relatively stable forest requires about 200 years when conditions are favorable.

Figure 30.—*Old field development or succession in New England begins when abandoned fields are invaded by grasses, forbs, and woody plants such as black cherry and redcedar* (left and center); *it terminates in a dense forest of hardwood trees* (right).



Old field succession in the Southeast (fig. 31) typically passes from communities of grasses and shrubs to loblolly pine, and finally to a relatively stable forest of pines, oaks, and hickories. This process requires 150 to 200 years. This is a good example of *secondary succession*—development that occurs after an established community has been removed or partly destroyed. Succession where no organisms existed previously is called *primary succession*.

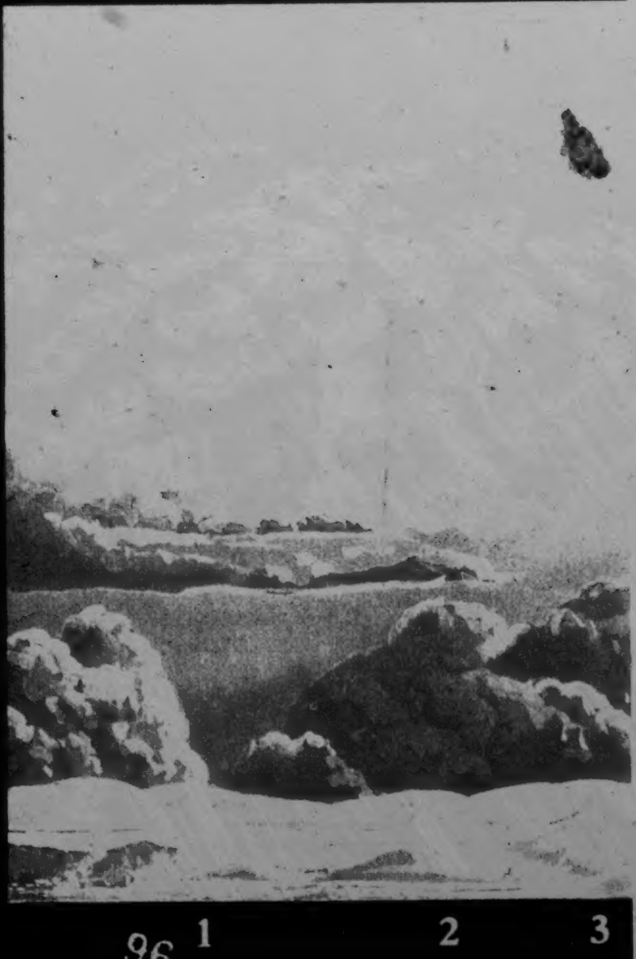
Figure 31.—*Old field developments in the Southeast includes grass and shrub communities* (center foreground), *pines* (background), *and sometimes terminates in a forest of mixed pines, oaks, and hickories* (far right).



Lake Michigan sand dune

Figure 32, an example of primary succession on sand dunes along Lake Michigan, demonstrates the powerful ability of vegetational communities to modify a harsh environment. As the lake retreated and became smaller over thousands of years, a series of sand dunes was successively exposed. Studies of these dunes have shown that, beginning with bare sand (1), different communities develop—beach grass (2), shrubs (3), cottonwood (4), jack pine (5), and, finally, an oak forest (6). Primary succession is much slower than secondary succession; in this example, the process may require about 1,000 years.

Figure 32.—*It takes about 1,000 years for vegetational communities to colonize newly exposed sand beaches (1) of Lake Michigan and finally develop into an oak forest (6). On successively older dunes, plant communities change from grass (2), to shrubs (3), to cottonwood (4), to jack pine (5), and, finally, to the oak forest.*



Bare rock

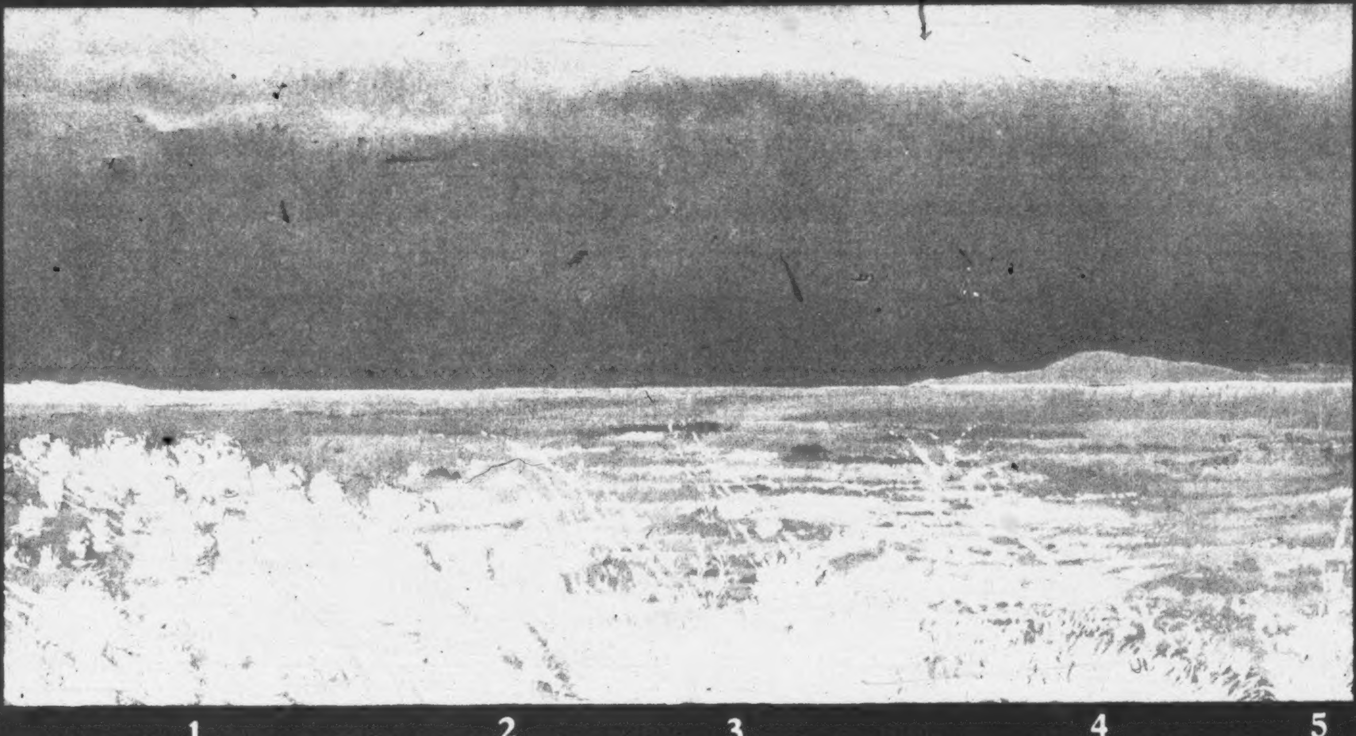
The harsher the environment, the longer succession takes. The conversion of bare rock to forest requires thousands of years (fig. 33). Succession begins when lichens etch and dissolve minerals from rock surfaces. When conditions are favorable, this action and the physical presence of the lichens may provide conditions which allow mosses to grow and accumulate organic and mineral matter. In this way, sufficient soil can accumulate to provide habitats for ferns and, later, for grasses and forbs. There are probably cases where such succession has continued to the point where shrubs and trees can grow.

Figure 33.—*Primary succession in mountains such as the Rockies begins with bare rock. Lichens* (left foreground) *may eventually create places where mosses* (center foreground) *can grow. Finally, many thousands of years later, a community of ferns, forbs, and grasses may evolve* (right foreground). *If conditions are very favorable, a community of shrubs and trees may eventually develop.*

Grassland

Succession, of course, also occurs in nonforest ecosystems, including large lakes, oceans, and grasslands. Figure 34 shows grassland development on wagon trails in the western Great Plains after these trails had been abandoned for different lengths of time. For the bare ground of the most recently used trails (1) to pass through communities of scattered annual weeds (2), short-lived grasses (3), and early perennial grasses (4) to the original dense, stable grass community (5) requires 20 to 40 years.

Figure 34.—*Succession on abandoned wagon train trails in the Great Plains. The bare soil (1) of the most recent trails first supports scattered annual weeds (2), then short-lived grasses (3), and later early perennial grasses (4). From 20 to 40 years after abandonment, the trails once more support the original dense grass climax (5).*



Succession also occurs in less visible places. Many different communities of soil insects and microorganisms developed during the transition from bare dune sand to the moist organic matter-rich soil of the forest. Even wounds in living trees, like bare fields, are colonized successively by communities of microorganisms; this colonization usually begins with "pioneer" bacteria, followed by staining fungi, and eventually by decay fungi.

Succession of Saprotroph decomposer communities within a fallen tree (fig. 35) begins when the dead wood is attacked by insects and microorganisms, and ends when the wood is decomposed by wood-rotting fungi, bacteria, and other Saprotrophs.

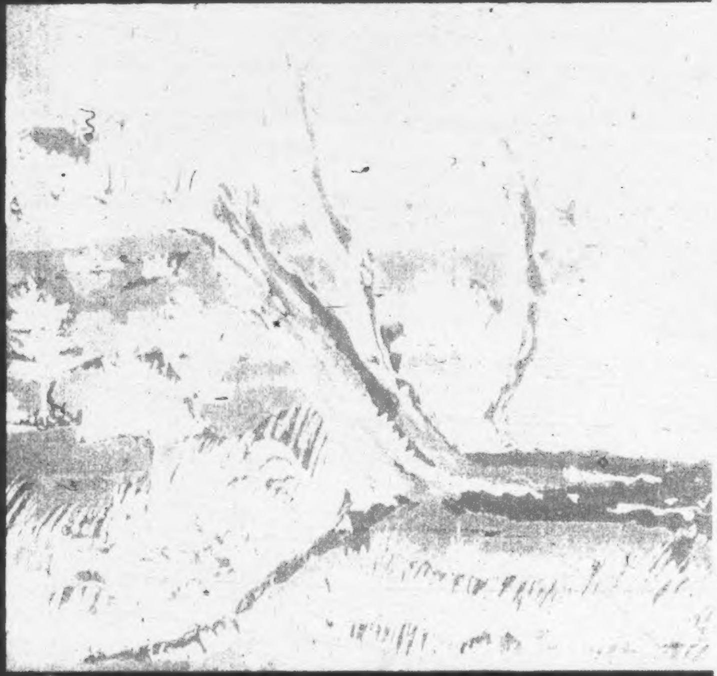


Figure 35. — *Succession in a fallen pine tree.*

FACTORS AFFECTING SUCCESSION

Successions of birds and animals also occur—usually as a result of changes in the plant community. And animals and birds can significantly affect the course of succession. Birds and animals often introduce seed from plants of more advanced stages, and burrowing animals provide habitats of mineral soil for plants of earlier stages. In mixed plant communities, overbrowsing of early stage species by herbivorous mammals and insects can speed up succession. But, overbrowsing in general usually sets succession back to an earlier stage.

Succession also can be set back by other major disturbances—both natural and human-caused. Fires, hurricanes, and logging operations are some of these disturbances.

But we might ask ourselves, so what? What is actually happening ecologically when the Game of the Environment is played by nature's Rules? Why is this important to people? We can provide some answers to these questions by comparing the early and late stages of succession.

SUCCESSION VERSUS PRODUCTIVITY

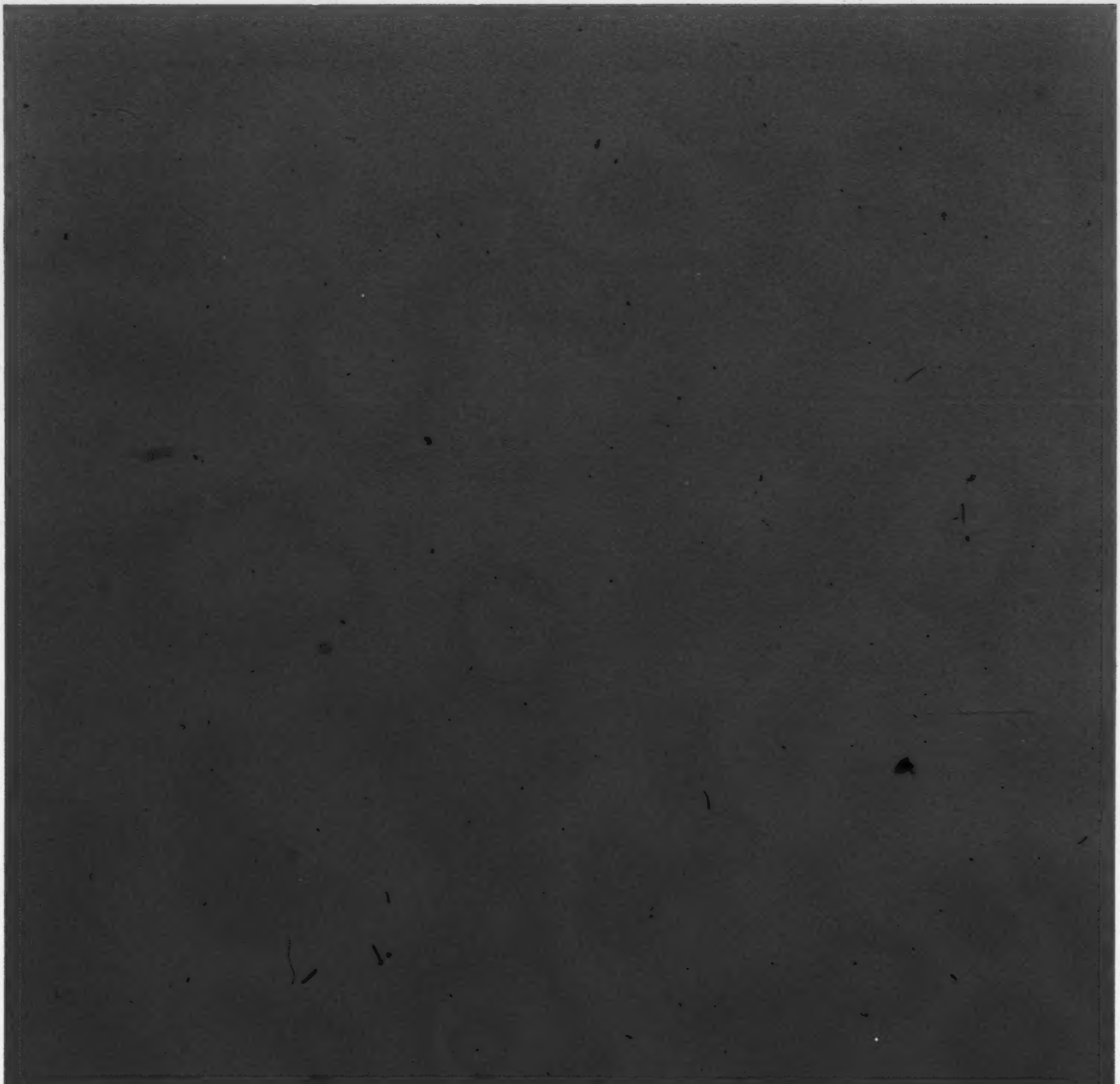
In the early stages of community development, materials produced by photosynthesis accumulate faster than they can be degraded through respiration. Energy flows primarily by the grazing process in short, simple food chains.

As biotic development proceeds and biomass increases, respiration also increases; eventually the production of materials by photosynthesis may nearly equal that being degraded through respiration. Energy is channeled by complex pathways through intricate food webs that mostly entail breakdown of detritus by Saprotroph decomposers.

PEOPLE AND SUCCESSION

The characteristics and principles of ecological succession are very important to us. In most cases, modern agriculture and forestry rely on holding natural biotic development in check, or interrupting it at some point and starting it again. Thus, we grow simple communities—often single species or *monocultures*—over large areas. Experience has shown that these systems are very vulnerable. They can be hard hit very quickly by insects and disease or by drought or other adverse environmental factors so that we must continually subsidize them with energy in the forms of pesticides, fertilizers, and fossil fuel. Therefore, to supply the food and fiber needs of today's population, we must break the Rules of the Game that regulate the development of natural ecosystems.

At the same time, we are beginning to understand that natural ecosystems also fulfill needs that are important—the modification of harsh climates, the cycling of nutrients, and the production of clean water. And, of course, the recreational and esthetic needs of people are often best satisfied by natural ecosystems. A logical strategy is to maintain diverse mixtures of early and later "stages" by compartmentalizing the landscape.



IN YOUR ENVIRONMENTAL ARENA

☐ For some natural ecosystems in your area, describe some of the steps that you can see in the biotic development (succession) of the plant communities.
☐ For your area, list some plant communities whose development is regulated or held in check by people. How and why are these communities regulated?
☐ Compare a natural and a people-regulated plant community in your area in terms of the numbers of different plant and animal species present, the sources of energy, and the sources of nutrients.
☐ Describe some ways that succession, or biotic development, has determined your lifestyle or those of members of your community.

104

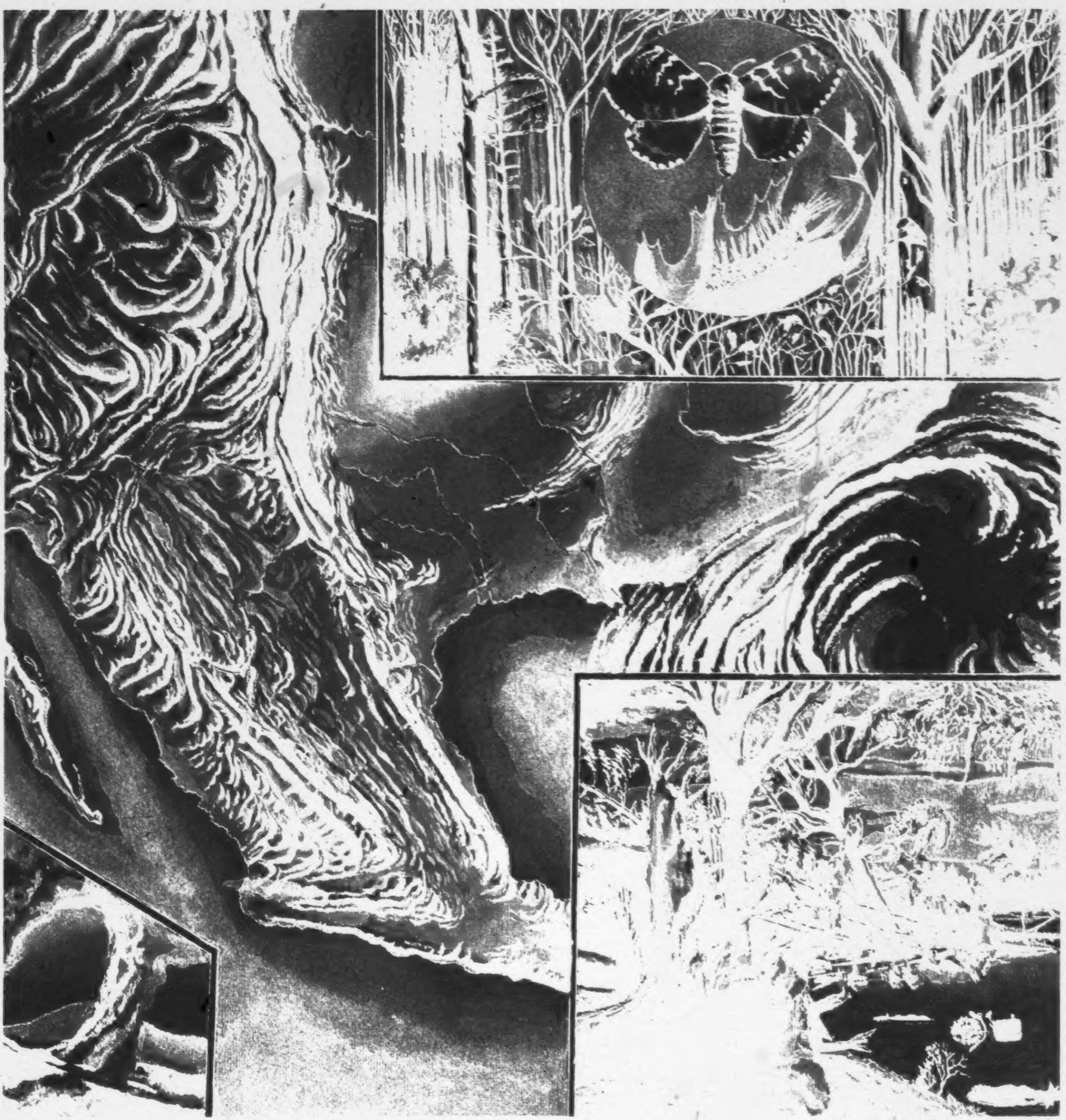


Figure 36. — *Wildfire may be a powerful natural Foul in that it interferes with the nutrient cycling and energy flow Rules. Some natural communities exist because fire "breaks" the Rules.*

SOME OF NATURE'S FOULS

The successional patterns of the natural ecosystems just described occur when the Game of the Environment proceeds unhindered by major upsets. But upsets are common and natural. Defoliation by insects in the Northeast, hurricanes in the Southeast, wildfire in the West, drought in the Plains, and volcanoes in Central and Latin America are some natural events that interfere with (break) the energy flow and nutrient cycling Rules of the Game.

Wildfire

Wildfire (fig. 36) has a powerful influence on patterns of vegetation. Fire sets back succession and influences species composition. Some species are favored by fire; others are hindered or are eliminated.

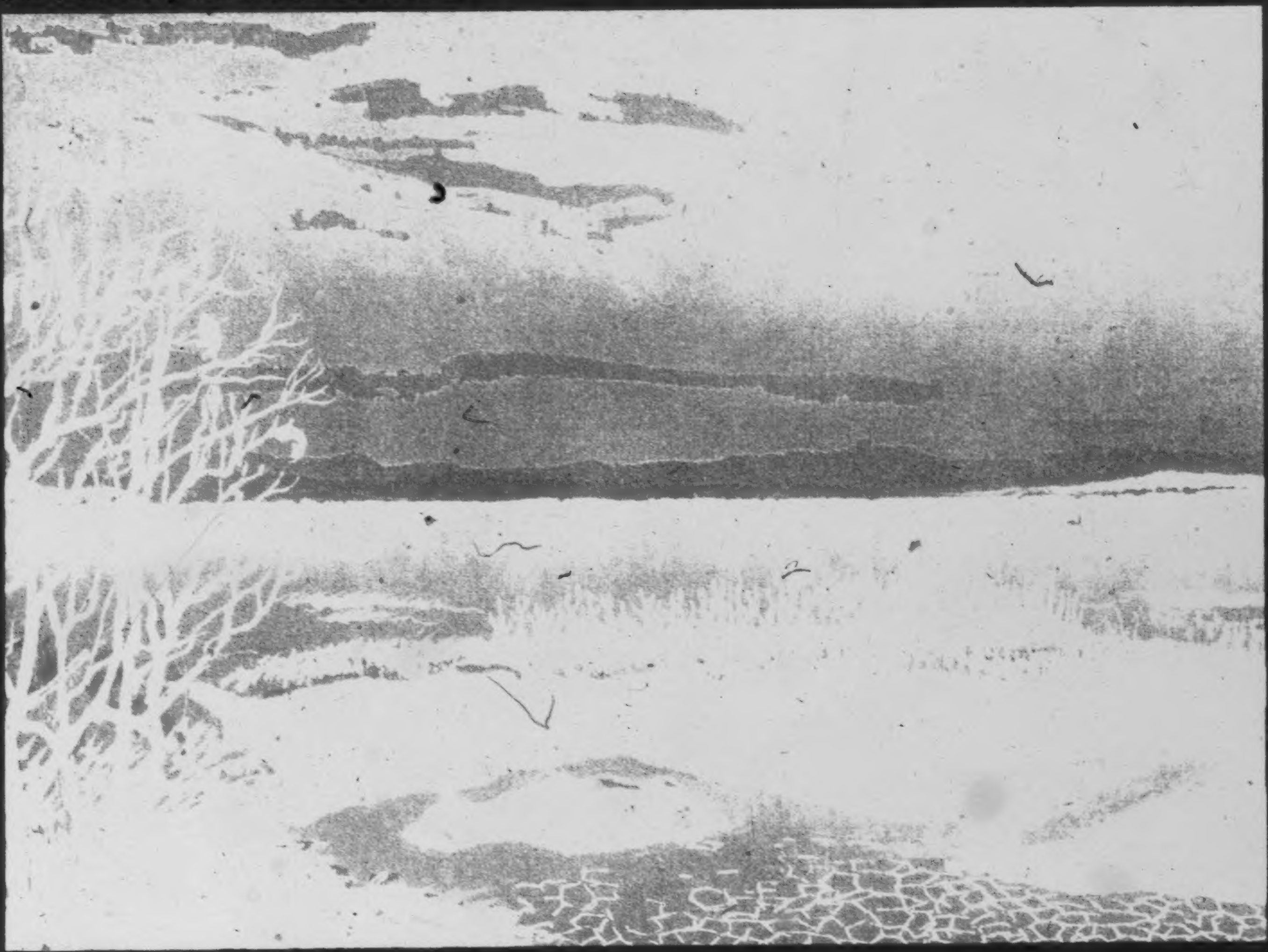
Fire is a major agent in decomposing organic matter and in recycling nutrients. Periodic fires preserved the vast prairies and oak openings of yesteryear; they are responsible for maintaining the shrubby California chaparral, the jack pine forests in the Midwest and in Canada, and the mixed pine flatlands of the Southeast. The important role of wildfire in natural systems is now being recognized; under certain circumstances, fire in wilderness areas is permitted to run its course.

Fire has long been exploited by people—primarily in setting back succession to a more productive stage. Foresters use controlled ground fire to suppress hardwoods in pine forests, to create openings and food for wildlife, and to reduce accumulated litter. Thus the use of fire prevents catastrophic hot crown fires and perpetuates useful shrub species, such as blueberry and huckleberry, which serve as food for wildlife and people. Fire is used to recycle nutrients in grass communities, to eliminate encroaching weed shrubs, and to reduce the number of disease organisms on stubble and other plant parts after harvesting.

Drought

Drought (fig. 37) also has greatly influenced the development of ecosystems. The severe drought of the 1930's caused widescale alterations in species composition, and major disruptions of communities. As plants died, their roots were no longer able to hold the soil—the result was massive erosion of topsoil rich in nutrients and organic matter. During this period, succession was often set back to "square one"—bare subsoil.

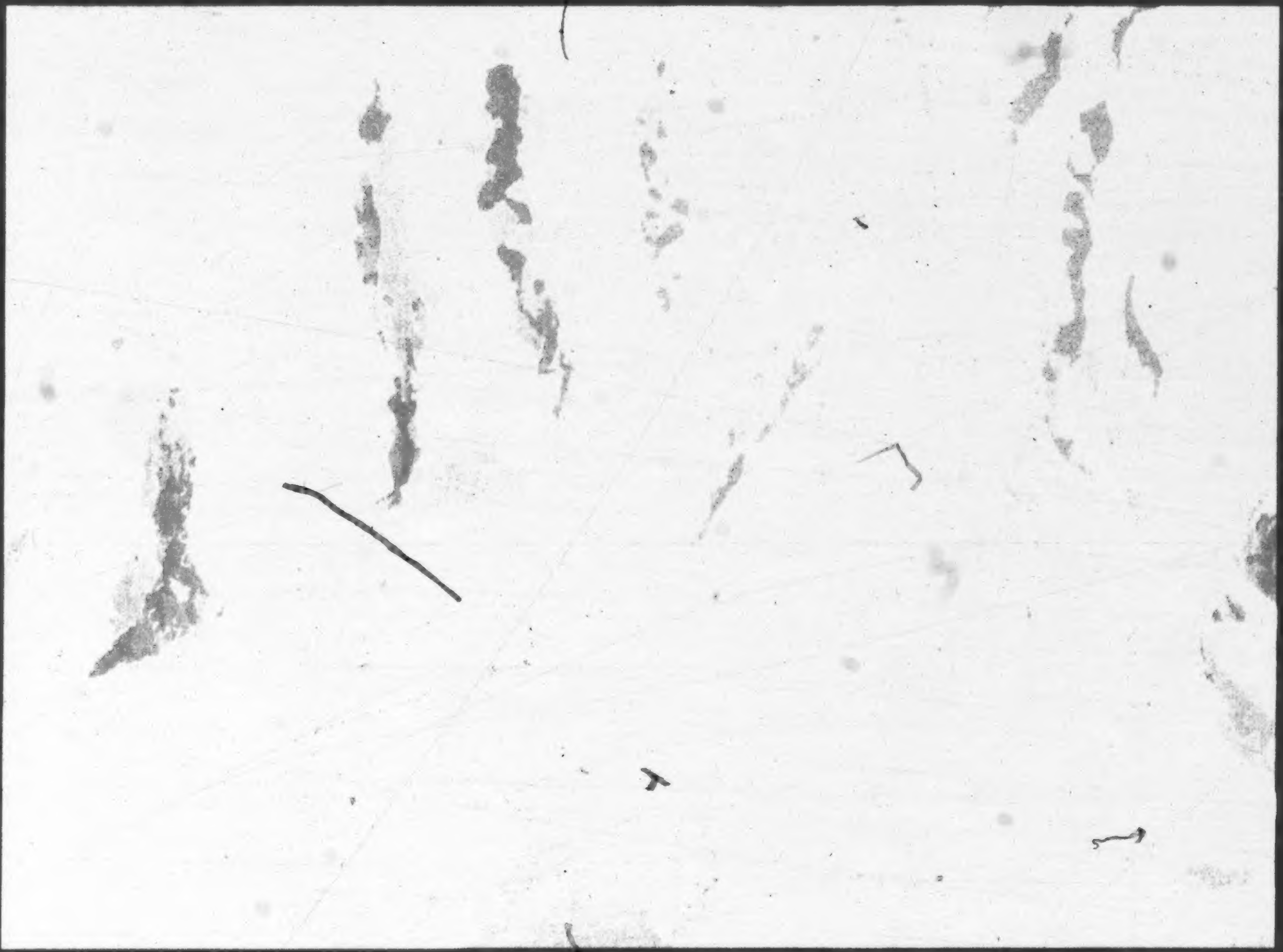
Figure 37—*Severe drought is a natural event that results from disruptions of the water cycle, and that, in turn, interferes with the cycle of nutrients and flow of energy in ecosystems.*



Volcanism

"Square one" also is the successional stage after volcanism (fig. 38). Bare volcanic rock may suddenly appear where only minutes before grew lush tropical or subtropical vegetation; also, volcanoes are natural sources of pollution because they emit particulates, heat, and gases.

Figure 38.—*A volcano may suddenly and violently set back succession to "square one," or bare subsoil.*



Hurricanes

Powerful hurricanes, tracking north and east from their spawning grounds in the Caribbean, periodically "sweep" the forests along the southern and eastern coasts of North America (fig. 39). Records suggest that hurricanes remove the "big trees" of the eastern forests every 100 to 150 years; when this happens in mature climax forests, the light that reaches the forest floor allows light-demanding plants to grow on mounds of soil raised by the tipped roots of the toppled giants. In this way, hurricanes (and other wind storms) create a diversity of species by providing gaps for species that demand light.

Figure 39. — *Hurricanes periodically interrupt or influence succession in North America.*

Overgrazing (insect defoliation)

"Overgrazing" by defoliating insects also can disrupt natural forest ecosystems. Defoliation—removing the food-making machinery—seriously interferes with energy flows. The ingestion of leaves that otherwise would have fallen and decomposed interferes with normal nutrient cycles. Periodic severe outbreaks by insects such as the gypsy moth (fig. 40), spruce budworm, tent caterpillar, and cankerworm can alter species composition significantly and influence succession.

Repeated defoliation of oaks by the gypsy moth may result in the death of significant numbers of trees; depending on the site and stage of development, defoliation also can advance or set back succession.

Figure 40.—*Defoliation by insects alters energy flow and nutrient cycling.*

Figure 41. — *Domestic and wild animals can overgraze their energy and nutrient supplies if they become too numerous.*

Outbreaks of gypsy moths are frequently associated with a previous disturbance in the forest caused by humans or nature. Recent evidence that low populations of this insect are strongly regulated by predatory insects and small woodland mammals (deer mice and shrews) suggests that disturbances that reduce predator populations (for example, fire or urbanization) may indirectly trigger insect outbreaks.

Outbreaks by other grazer Consumers due to the control of predators are well documented. The unwise destruction of Consumers at the tops of food chains—wolves, coyotes, hawks, eagles—for sport or for protection of domestic and wild animals has resulted in explosions of grazing prey populations (fig. 41). In many instances, the outcome has been overgrazing and depletion of the range, and the starvation of these "protected" herds.

Similar consequences have followed the introduction—intentionally or accidentally—of herbivores into ecosystems that have no predators. Thus populations of the introduced gypsy moth seem to be explosively higher where the insect moves into new territories than where it has been established for many years. When plotted, such population patterns typically follow a J-shaped growth curve, the population rises exponentially until the resources of the environment suddenly become limiting. When this point is reached, the population usually crashes to a low point. With time, subsequent oscillations in populations of some organisms may become less violent, and population levels fluctuate near the maximum number that can be supported by the given habitat. This population level is known as the *carrying capacity*.

Carrying capacity is an important concept. Basically, it tells us that there can be only so many Players of one kind in an Arena. The J-shaped curve is the growth form of populations not responsive to the carrying capacity. Often, however, increasing populations do respond to increasing environmental limits. In these cases, the shape of the population growth curve is an S; it begins slowly, then increases rapidly, and later, as resource limitations provide negative "feedback," levels off near the carrying capacity.

It is important to point out that outbreaks of native insects occur periodically, and that they may contribute in major ways to the development of an ecosystem. In the terminology of our Game, these Consumer Players, by interfering with the flow of energy and nutrient cycling (excessive grazing versus the normal slow decomposition of detritus), can alter succession. Outbreaks of the spruce budworm, like fire in the jack pine forests, are believed to be the primary agents responsible for periodically killing off, renewing, and thus perpetuating the northern spruce-fir "forest of catastrophe."

The human need for a predictable and continual supply of wood led to attempts to alter these natural outbreaks—primarily by controlling insect populations with chemicals. But widescale use of certain pesticides brought other adverse effects (see pages 132 and 133).

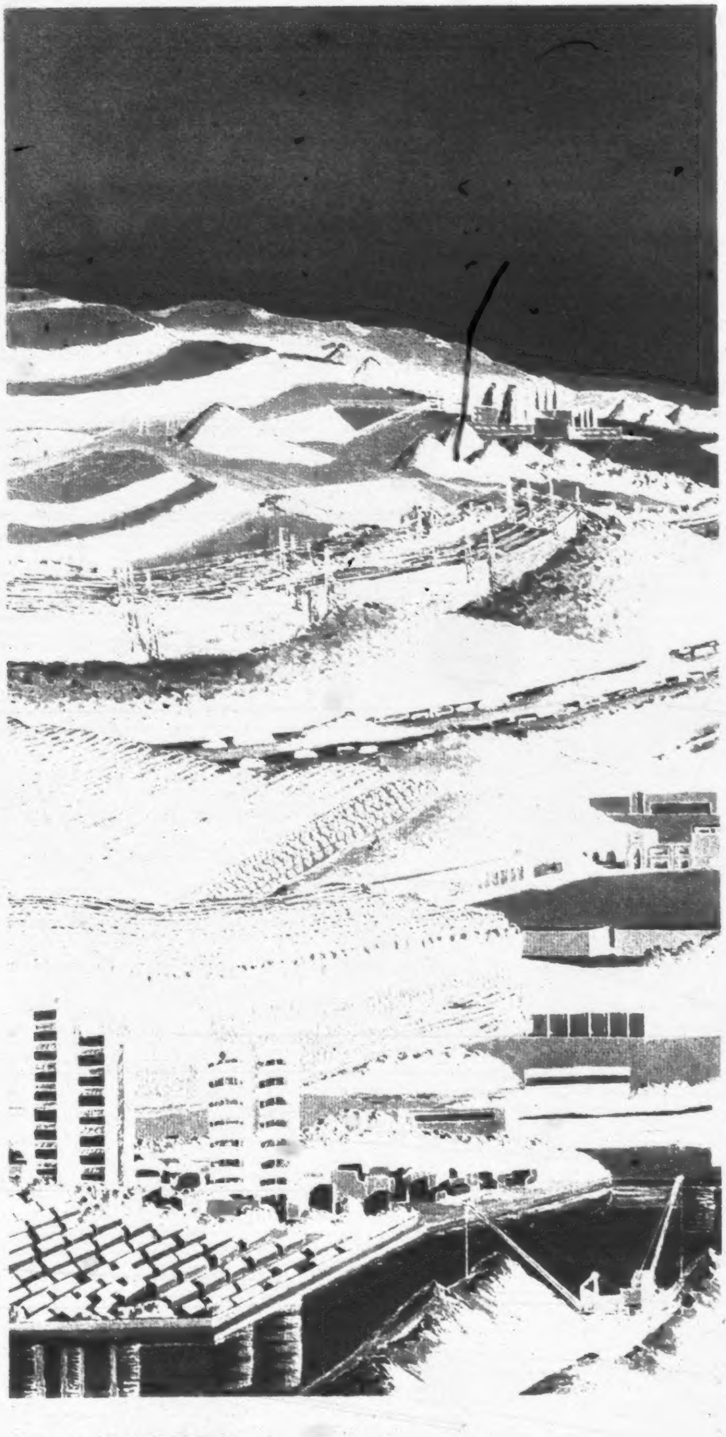
IN YOUR ENVIRONMENT ARENA

☐ List some other natural events (Fouls) that have interfered with energy flows or nutrient cycles in our country.
☐ What natural Fouls have you encountered in your community?
☐ In what ways have they interfered with the Rules of the Game?
☐ Describe the ways in which succession could have been affected by one of these events.
☐ How have people's activities or plans been influenced by natural events in your area?

SOME PEOPLE FOULS

Like nature's Fouls, the adverse effects of human actions are primarily due to interfering with and breaking the Rules of the Game—to messing up the natural order of things. Our general view of these environmental "problems" is intended to serve not as a warning of impending doom but as a guide for future action. We have an unequaled capacity to wreak havoc with our environment and, therefore, to endanger ourselves. But we also have the capacity—unique among all creatures—to evaluate and correct past mistakes. Our future course must be guided by hindsight and by an understanding of ecological relationships.

The unparalleled ability people have to "move things about" has created adverse and complex situations that must be faced by future generations. Figures 42 through 58 summarize some of our Fouls and Penalties as we *manipulate ecosystems, deplete finite resources,* and *pollute our environment.* That all of these actions are closely interrelated emphasizes once more the interdependence of ecosystems and of events within them.



Manipulation of Ecosystems

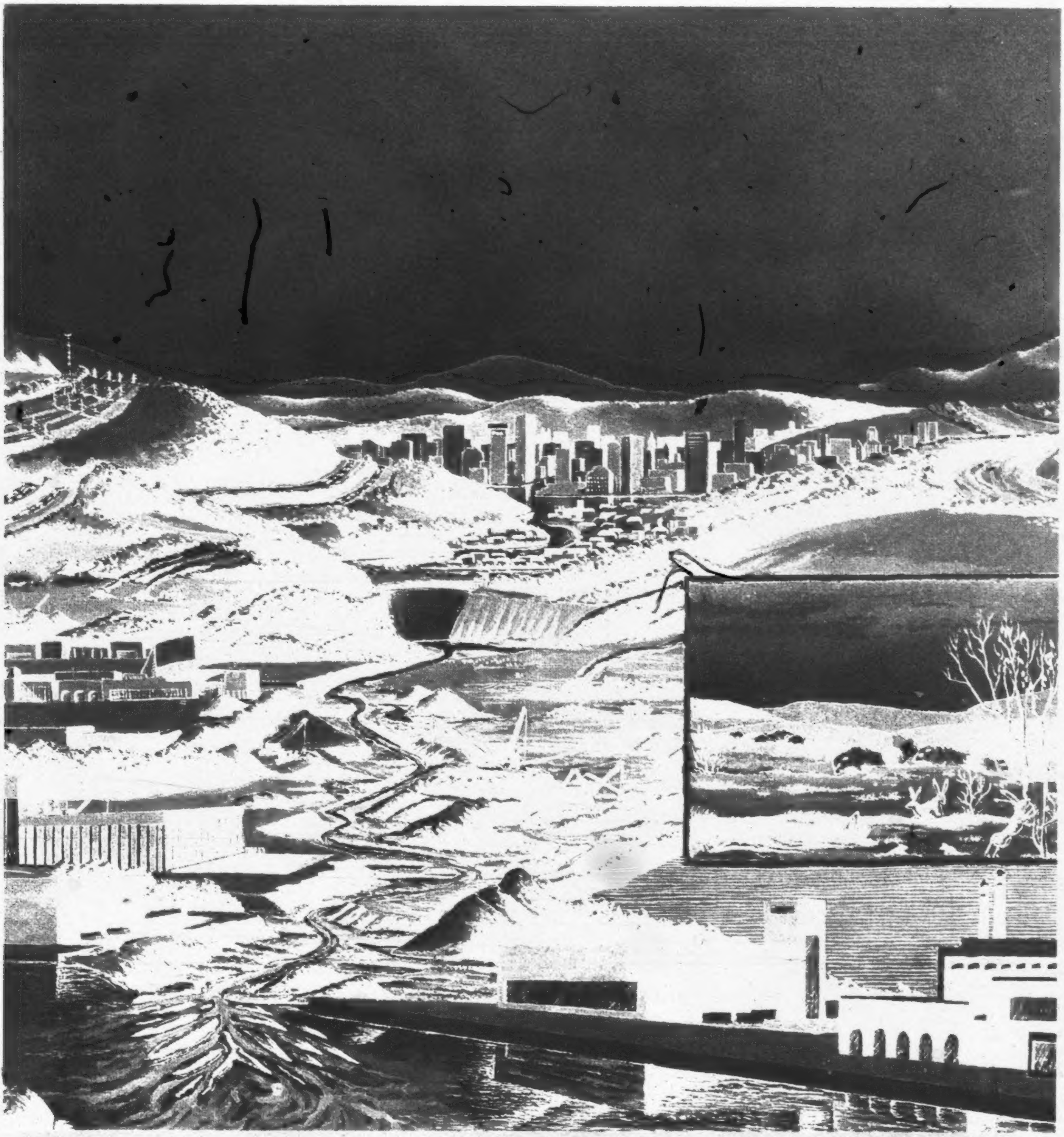


Figure 42. — *People often move too much, too often, and in too little space. Domestic and industrial development of the flood plain and improper strip mining on the hills above can create serious flood and siltation problems.*

2

Manipulation of ecosystems

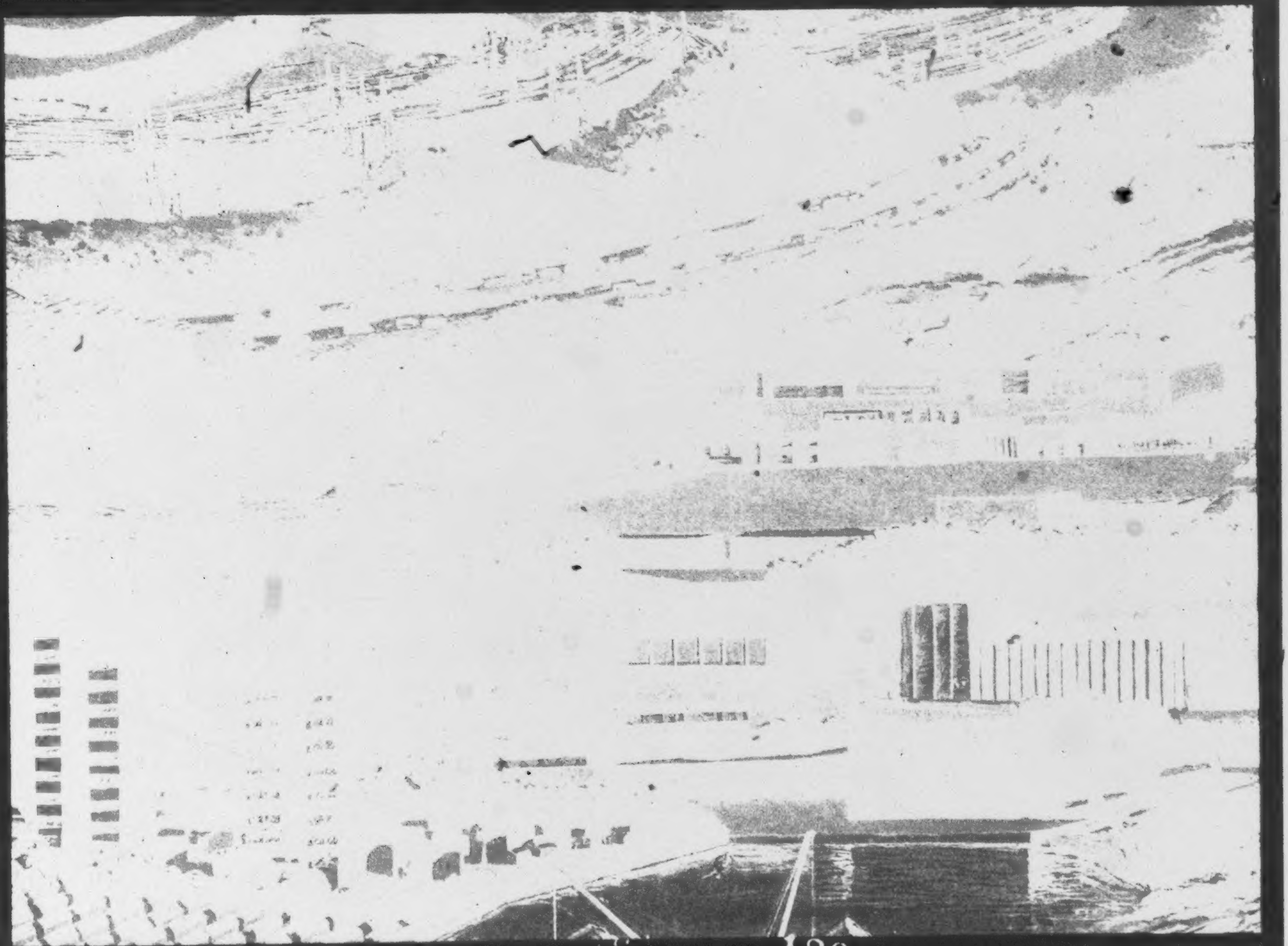
Disruption of flood plains

Let's consider the following scenario centered on the City and the river around which it was built (fig. 42). Initially the source of power, transport, food, and water (upstream) and waste disposal (downstream), the river is now a "problem." Encroachment by buildings, shopping centers, and highways onto the river's flood plain have created a flood problem; this requires the construction of a dam—the "solution." But siltation behind the dam from upstream developments is now decreasing the effectiveness of the dam. Downstream, the false security created by the dam's presence encourages further clearing, filling, and developing of the convenient flood plain land and the surrounding watershed. Housing developments and industrial complexes encroach even onto the salt marshes. Destruction of the marsh "nurseries" brings about the demise of the once thriving sport fishing of the harbor. And runoff from nonabsorptive surfaces and erosion accelerates silting of the harbor—a problem that is "solved" by dredging.

Dredging and dumping

But a new problem arises: what to do with the dredged spoils? Previous solutions, returning the spoils to land to fill "waste spaces" such as wetlands or dumping them at sea, are now questioned because of their adverse environmental impact.

Figure 43.—*Outbreaks of diseases and insects (group of yellow trees on hillside,* left center*) can occur when trees are rendered susceptible to them by factors such as pollution. This can be especially serious when too much of the same crop is grown in one area.*



Growing monocultures

In trouble now are the farmlands and the forest. Agriculture is relegated to less fertile land above the flood plain; farmers and foresters are forced to focus only on a few productive species. The growing of a single species to the exclusion of others on a large area is known as a monoculture.

There are outbreaks of bark beetles (fig. 43) in the pine forest monocultures weakened and predisposed to insect attack by air pollution, especially that from automobile exhausts. Harvests are now being conducted to salvage the dead and dying trees. Improperly installed logging roads used in this operation augment erosion and silting of the harbor. Air pollution also affects the agricultural food crops "downwind" of the city. Impacts on the city's food source will be great if the monocultures are susceptible to the high levels of oxidents reached during "episodes" of inversion (air trapped under a warm upper layer that prevents the pollutants from rising). (See page 141.)

Strip mining

When the city's demand for energy exceeds the river's capacity to produce it, the search for other sources leads to the coal in the hills to the west (fig. 44). Now the unreclaimed spoils disgorge their acids into streams and the river, eliminating them as sources of potable water and desirable fish species.

Excessive predator control

On the hills to the east, sheep that were "protected" when their predator—the coyote—was poisoned now must compete with high populations of rodents (fig. 45). The consequent overgrazing and deterioration of the range leads to the elimination of plant cover and to erosion.

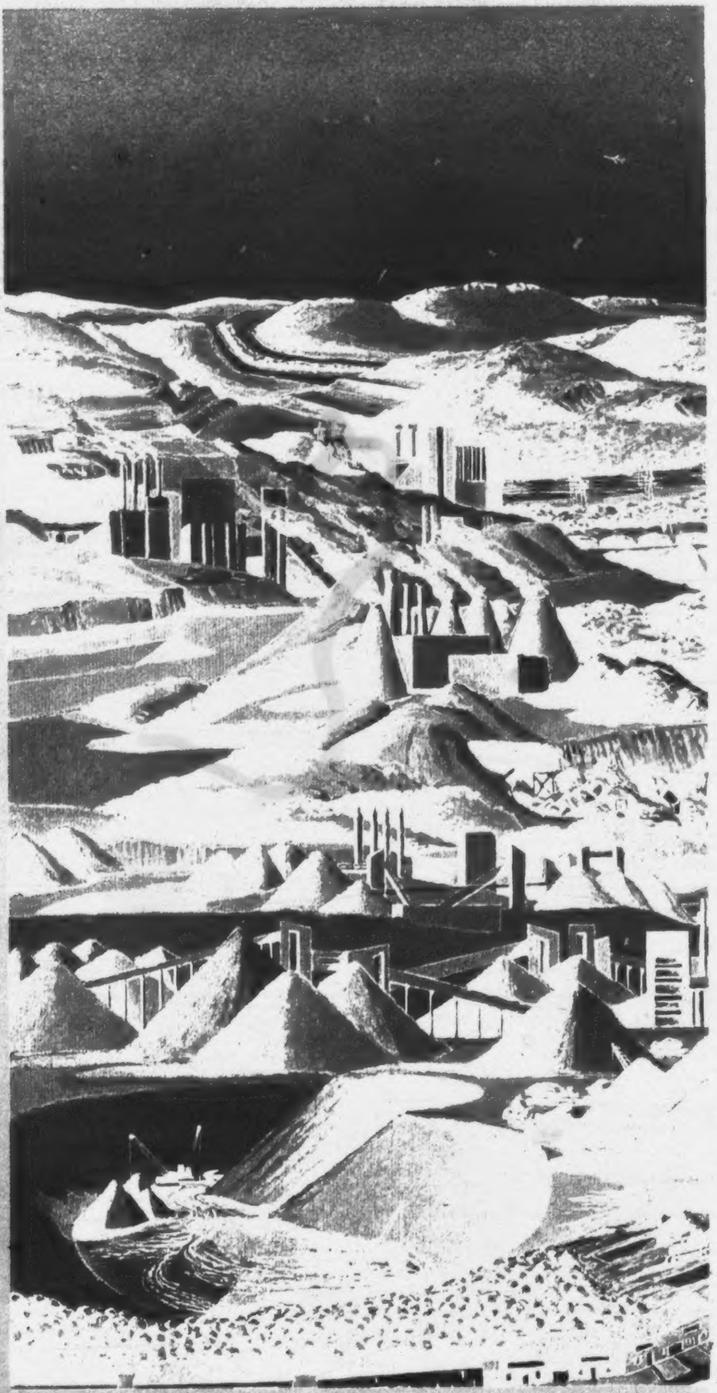
Thus by merely moving things about and by "shaping" nature to suit our immediate needs in what seemingly is the most practical manner, we have often created problems—and the solutions, in turn, have created additional problems. As a powerful geophysical agent, we can counter natural succession, block critical steps in important food chains, and modify natural habitats.

Figure 44.—*Unreclaimed strip mines—a blight on the landscape.*

IN YOUR ENVIRONMENTAL ARENA

- ☐ What "manipulation" Fouls have been commited in your community?
- ☐ Describe some consequences of these Fouls.
- ☐ How could they have been avoided?
- ☐ How can they be corrected?
- ☐ How would the "corrected" Fouls change lifestyles in the community?
- ☐ How would your family's activities be affected?

Figure 45. — *"Protecting" herds of grazing animals by removing their "predators" can backfire when competition by other grazers results in destruction of the natural range.*



Depletion of Finite Resources

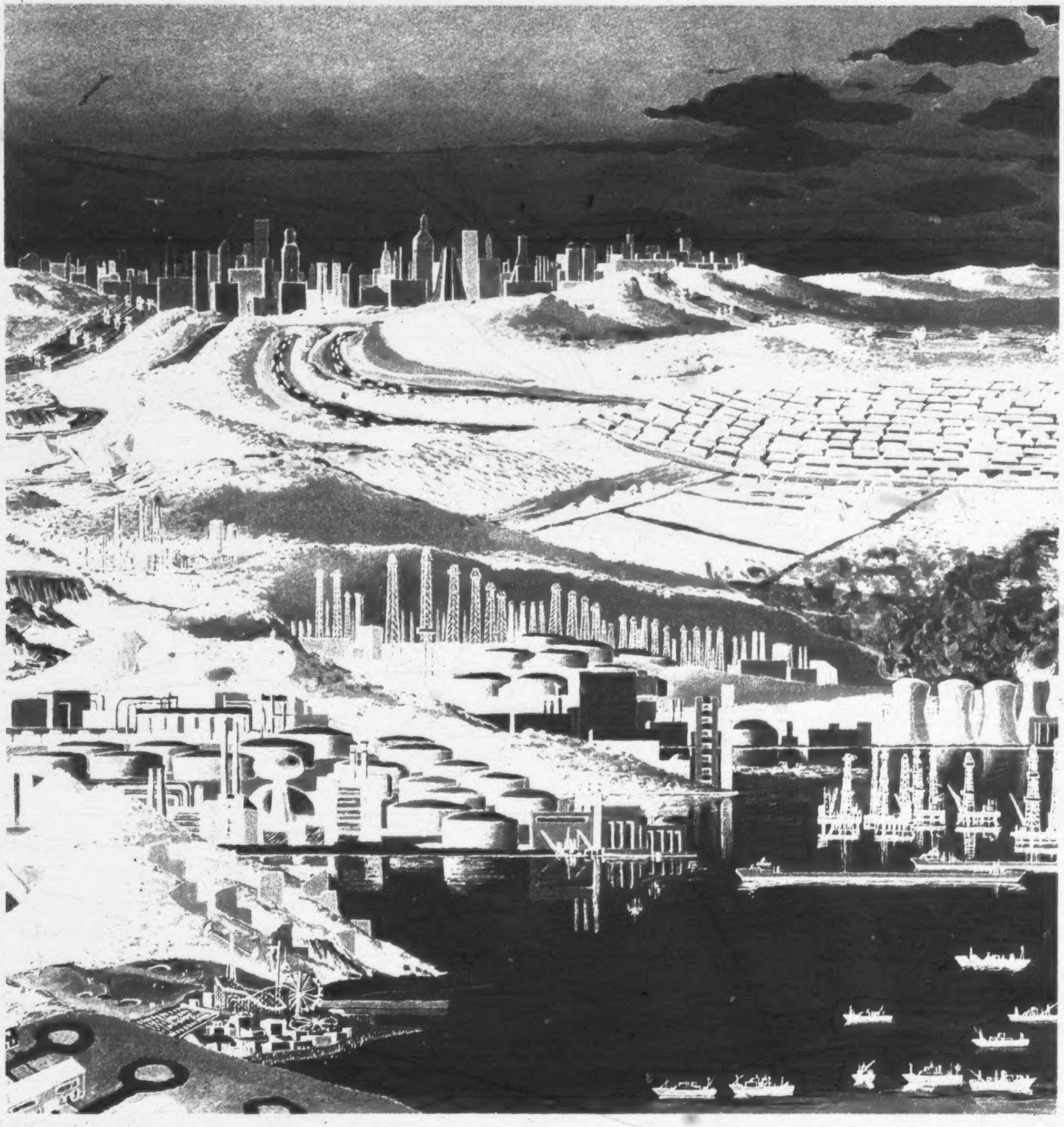


Figure 46. — *Huge acreages of valuable agricultural land are lost each year to housing developments, highway, and industrialization.*

Depletion of finite resources

As the "Grand Exploiters," we now face a world soon to encounter shortages of its available minerals, metals, fossil fuels, and—if we do not act now—agricultural lands.

Agricultural land, forests, open space

Linked closely to the manipulation of the environment is the constant depletion of our most valuable finite resource—land. It is necessary, of course, to change land uses as our population increases, but we must do this wisely. Each year, in the name of "progress," we pave over, build on, or otherwise remove forever thousands of acres of productive land. As was noted earlier, some activities—building on flood plains and filling of inland wetlands and salt marshes—produce adverse effects that are complex and far-reaching.

The removal of productive farms and forests, now proceeding rapidly in highly populated areas of the United States (fig. 46), may directly affect our well-being. The current trend of concentrating food production in limited geographic areas that are often far from population centers may prove unsound as transportation and storage costs increase and as regional crops fail due to climatic disasters or disease.

How much land is needed for agriculture, forestry, or protective open space? How should we ensure that sufficient amounts be maintained? These questions are extremely difficult to answer. It is often not recognized that much more space is demanded by each person in an affluent nation such as ours than is needed in poorer nations. This is due to the foods we desire, the fiber we use, and the human services we demand to maintain our standard of living.

Some ecologists have recommended that at least one-third of all land be maintained as open space. Whether or not this figure is the goal we should strive for, the current rate of land use changes and the projected doubling of our population in 25 to 45 years make it imperative that means be developed to ensure that the destruction of our productive agricultural lands is halted.

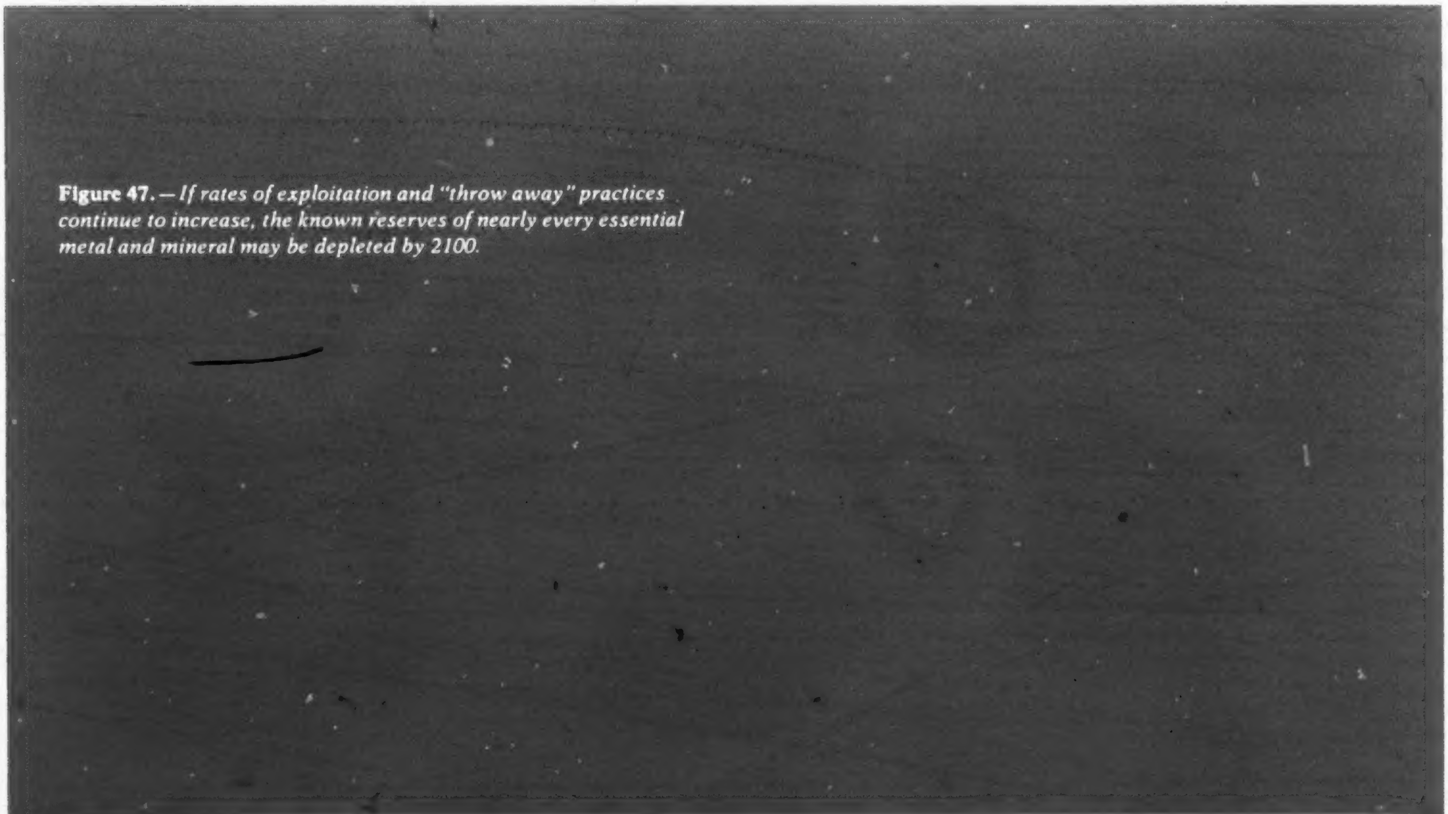


Figure 47.—*If rates of exploitation and "throw away" practices continue to increase, the known reserves of nearly every essential metal and mineral may be depleted by 2100.*

Minerals and metals

We in the United States have used more minerals and fossil fuels in the last three decades than have been used by humanity since time began! Our mineral resources *are* running out (fig. 47). If exploitation increases at its present rate, and if we continue our "throw away" practices, those of us still alive in the year 2000 may see the last of the copper mines close—and before them, the last lead, tin, zinc, silver, mercury, and gold mines. And the reserves of most of the other essential minerals and metals possibly could be depleted by 2100.

The hard truth is that the United States, Japan, and the affluent industrial nations of Western Europe import much of their key minerals from other countries—primarily the less developed nations. (Exceptions are the U.S.S.R. and mainland China.) The dependence of the United States on other countries for necessary minerals will increase dramatically: within the next decade we will have to import more than half of the 12 key industrial minerals.

As we learned earlier, in natural ecosystems the Game of the Environment continues because all materials needed for production are cycled within the system. But we have not yet learned this important lesson. We play the Game as if our mineral resources were infinite. Only a small fraction of the material we use is recycled. *Earthmanship*—playing the Game well—must be improved so that all necessary materials are recycled as fully as possible.

But even if recycling were perfect, it still would not provide the answer to our growing needs. Some mining would be required simply to replace materials lost to rust, corrosion, or wear. Along with a total commitment to conservation and recycling, we must give priority to improving mining technology, locating new reserves, and developing substitute materials.

But the problems encountered in playing the Game will be far from solved even if all of these activities are successful. While considerably less energy is required in recycling materials than in wresting them from virgin sources, the increasing *rate* of consumption means that ever increasing amounts of energy must be used. And energy *cannot be recycled*—it is a noncyclic resource. We do not have enough energy to extract resources, convert them to products, and then recycle them at increasing rates.

Energy reserves

Is there really an energy crisis? Are fossil fuel reserves being depleted? How soon will we run out?

Although coal has been burned as fuel for more than 800 years, it is only since the early 1800's that sizable amounts have been consumed. Fantastic increases in coal consumption accompanied the Industrial Revolution (250 million tons in 1870 to 2.8 billion tons in 1970); this dramatic increase occurred at the same time that the importance of coal was declining sharply in favor of oil and natural gas.

Indeed, oil production has doubled every 10 years since about the turn of the century (fig. 48). In the United States, oil production peaked around 1970, and we have been increasingly dependent on imports since. It is projected that world consumption of oil in this decade (1970 to 1980) will equal that used during the previous 100 years! Since we know that fossil fuel supplies are finite, the question of how long they will last is critically important.

The most optimistic estimates are that reserves of natural gas and "cheap" oil will be depleted (80 percent of total reserve used) by 2000 in the United States and about 30 years later in the rest of the world.

Figure 48. — *Massive oil fields on land and offshore, refineries, tankers, and tank farms point to our great dependency on oil and natural gas as major energy sources. It has been estimated that for all practical purposes, our reserves of natural gas and oil will be gone by the year 2000.*

The great hope for future sources of fuel seems to lie in our coal reserves (perhaps important for 200 to 300 years, but only 75 years if coal is the sole source of energy), and possibly in our vast deposits of western oil-bearing shales. But "switching back to coal" signals a potential increase in air and water pollution. Land reclamation, air pollution controls, safety measures, and shipping will generate additional costs.

And unlike its cost in the past, coal will be expensive. Gassification—producing synthetic natural gas (SNG) from coal—has been proposed as the answer to the high cost of shipping great quantities of coal from the West to the East. But SNG is much less efficient than coal or natural gas, and the necessary increasing in mining will deplete coal reserves sooner.

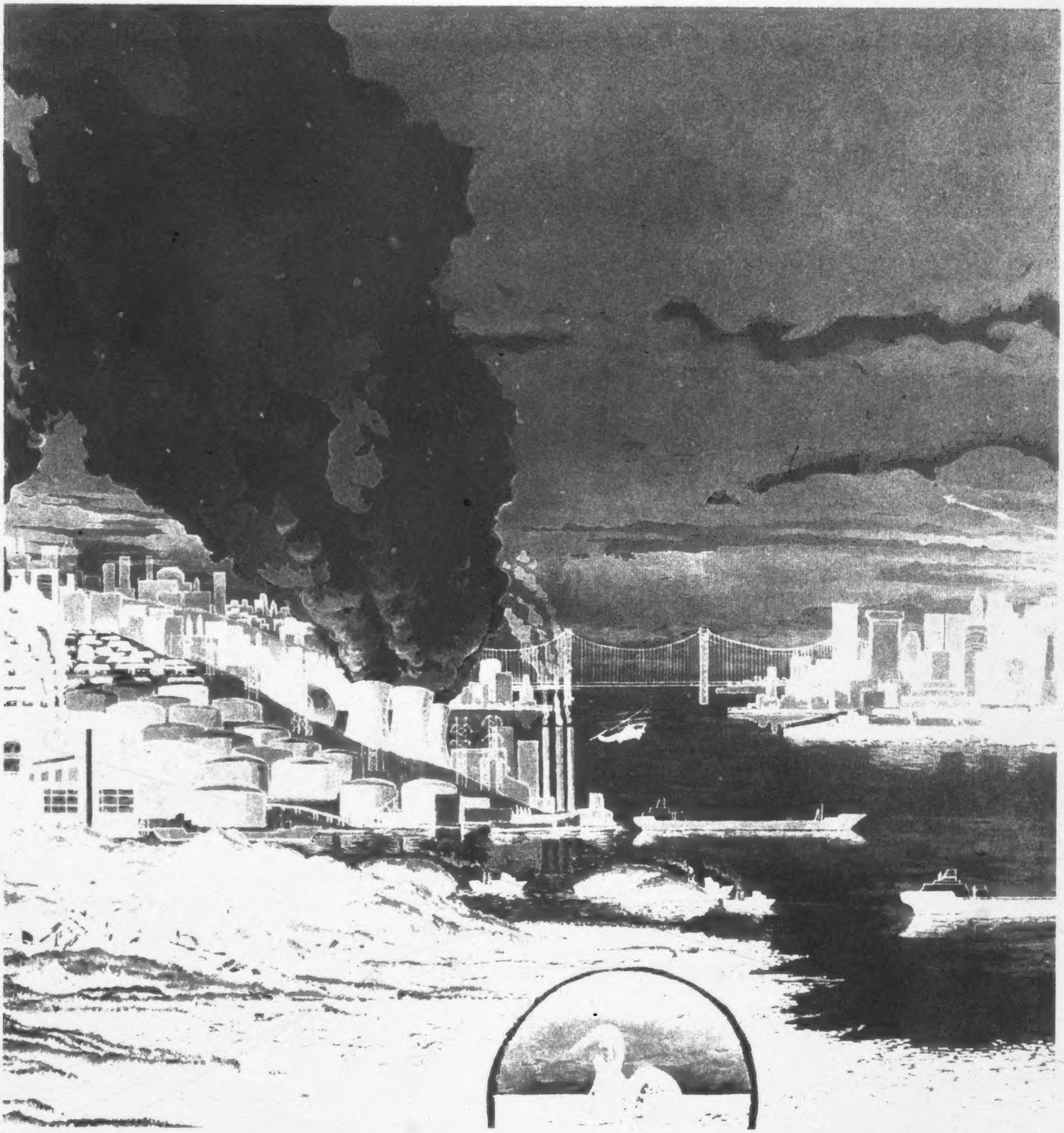
Similar disadvantages are associated with the exploitation of shale oil. The product that is sought, *kerogen*, is present in such low concentrations that huge quantities of rock must be ground and heated. The great amount of energy required for extraction and shipping will result in a low net amount of energy. And the impact on the environment is potentially very great. Great tracts of land will be disrupted and vegetation and wildlife destroyed. The quality of air and water will drop, as will water tables; and because the crushed spoils will occupy more than 10 percent more space than the solid rock, the waste disposal problem will be staggering.

These imminent shortages and escalating costs of fossil fuels have led us to focus on nuclear fuel for generating power. But the process currently used—fission of a relatively rare resource, uranium-235—is very wasteful. Uranium-235 makes up less than 1 percent of the uranium in natural ore. In fact, proponents of nuclear power fear that medium-priced supplies of uranium-235 may be exhausted before breeder reactors are developed to "breed" or make fissionable plutonium-239 and uranium-233. Either of these isotopes can be used as a catalyst to burn uranium-238 or thorium-232, which together represent an energy source millions of times larger than all known reserves of fossil fuel.

It would seem, then, that nuclear breeder reactors, and perhaps fusion reactors, offer the greatest hope for satisfying our insatiable appetite for energy. Unfortunately, as with fossil fuel sources, there are potentially serious consequences associated with nuclear energy—most of which relate to environmental pollution.

The possibility that human or technological error will result in a serious malfunction will increase as the number of reactors increases. This is perhaps sufficient reason to engage now in an integrated national energy program to develop technologies for alternative energy sources, especially solar, wind, tidal, and geothermal power. While nuclear energy probably will be a major, if not the primary, source of power in the decades to come, it would be technological insanity to put all our energy "eggs" in one basket—especially in the one that poses unparalleled potential for biological hazard.

Pollution



Pollution

Pollutants are materials injected into the biosphere in sufficient quantities to change the Game and to adversely affect the living Players, especially people (see picture on p.122). For convenience, pollutants are often classified as soil, air, or water pollutants, as biodegradable or nonbiodegradable, or as threshold (damaging at some level) or nonthreshold (damaging at any concentration). But pollution should be looked at as a whole, because what begins as an air pollutant often ends up in soil or water; and concentrations of substances damaging to one life stage of a Player organism may not be harmful to other stages or kinds of organisms.

Nature can be a polluter! Volcanoes, earthquakes, dust storms, and salt spray from ocean storms are major sources of natural pollution. Even wildfire and floods, whose effects may be beneficial, can contribute to air pollution or to undesirable siltation. But the intermittent and dispersed nature of these natural Fouls lessens their impact on the environment.

Figure 49. — *Too much phosphorus can trigger algal blooms in fresh water ecosystems, which, when extreme, can result in fish kills.*

People are the primary cause of pollution. Our actions as powerful biogeochemical agents—gathering, extracting, moving, concentrating, and dumping—have repeatedly swamped natural systems with too much material. We also have introduced many compounds that are totally alien to natural systems. Many of these substances are not biodegradable, and they accumulate or *magnify* in food chains until they become toxic. The chlorinated hydrocarbons (DDT, PCB) and radionucleids (strontium—90, cesium—130) are examples of introduced synthetic materials that now are distributed in significant quantities throughout the atmosphere. Thus, people can cause material cycles to "run amuck" by injecting into them excessive quantities of both natural and synthetic substances.

Figure 50.—*Runoff from animal feedlots carries excessive amounts of phosphates and nitrates into waterways.*

Figure 51.—*Sewage rich in detergents is a primary source of phosphate pollution.*

Some cycles run amuck

Phosphorus—Phosphorus is usually the element in short supply—the *limiting factor*—for growth of algae in fresh water. The rich green blooms of algae common in many of our rivers and lakes usually are signals that substantial amounts of phosphorus have been added to the system (fig. 49). Most of this excess phosphorus enters the cycle in treated or untreated sewage rich in detergents, and in runoff from animal feedlots (figs. 50 and 51).

The growth of algae Producers often proceeds unchecked until the excess phosphorus is used up and once again becomes limiting; then, a dieoff occurs. Because the decomposition of large amounts of dead algae requires large quantities of dissolved oxygen, fish may be killed.

Once phosphates reach estuarine or coastal Arenas, they no longer contribute to algae blooms; in these systems, nitrogen is the limiting factor. The suggestion that phosphate detergents be replaced with nitrogenous ones must be evaluated carefully because this substitution might seriously compound problems associated with explosions of phytoplankton and zooplankton in ocean ecosystems where nitrogen is the limiting factor.

Figure 52.—*As a result of human activities, the nitrogen cycle runs amuck (three boxes): In the atmosphere when nitrogen oxides help to form ozone and smog; and in soil and water when nitrate-rich effluents speed eutrophication.*

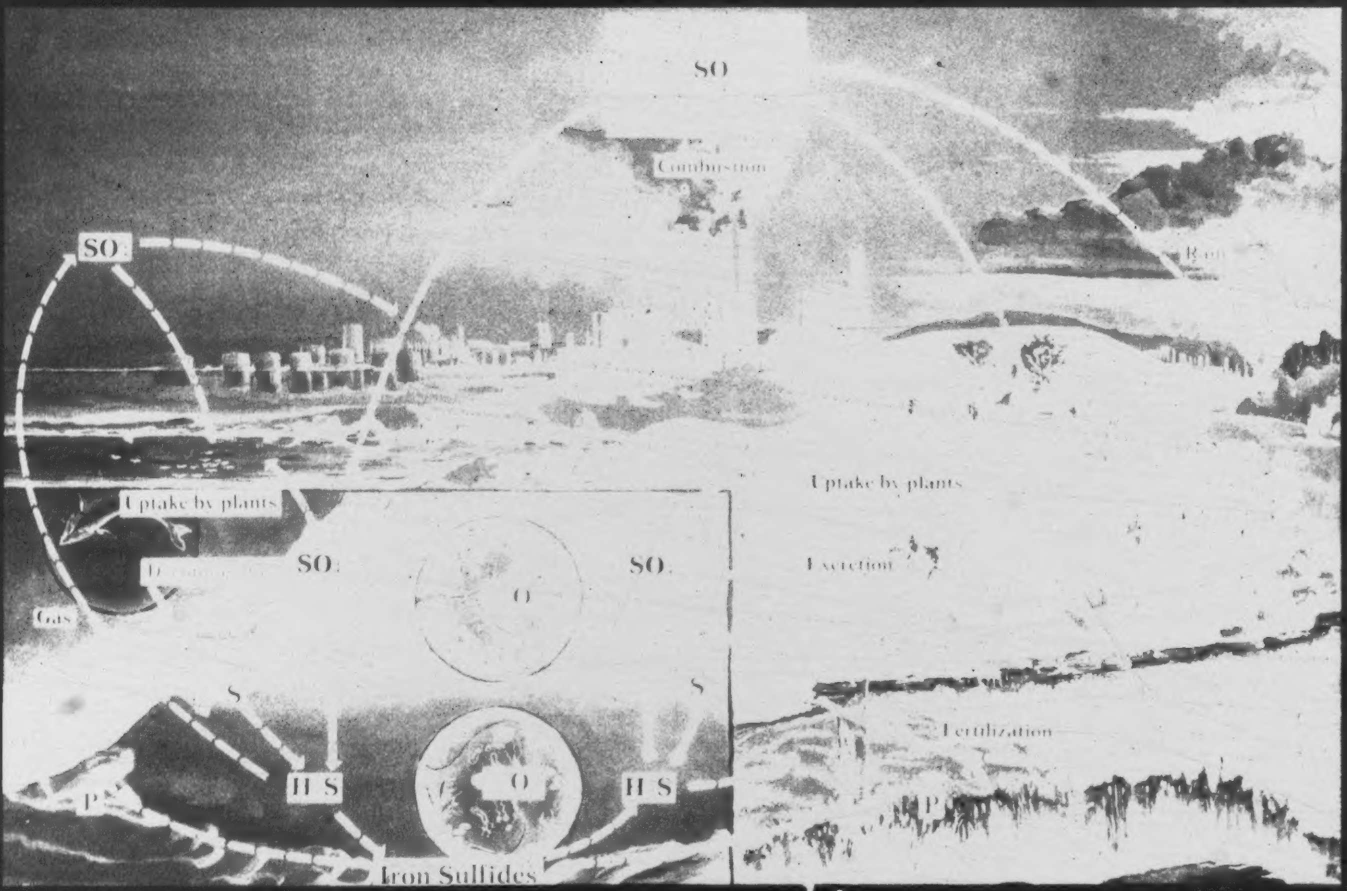
NO
Atmospheric Fixation NO
Industrial Fixation
NO, NH
Proteins
Biological Fixation
NH, NO
To ground water

Nitrogen. — Nitrogen monoxide (NO) and nitrogen dioxide (NO_2) are the two of the eight nitrogen oxides that contribute to air pollution. These gases are formed by the combustion of fossil fuels in automobiles and power plants (fig. 52). Combustion at high temperatures and pressure converts gaseous nitrogen to nitrogen monoxide and this, in turn, is oxidized rapidly by ozone (O_3) or slowly by oxygen to nitrogen dioxide. Nitrogen dioxide is reduced by ultraviolet light to nitrogen monoxide and atomic oxygen (O). The atomic oxygen can react with oxygen to form ozone or with unburned hydrocarbon emissions to form photochemical smog.

Nitrogen dioxide, ozone, and smog are harmful to plants and animals; they cause irritation of the eye, nose, throat, and respiratory tract, and they damage food crops and forests. The interaction of these pollutants with others, especially with carbon monoxide and sulfur dioxide, can cause great damage at relatively low concentrations.

As is shown in figure 52, the nitrogen cycle is carried out not only in the atmosphere but also in soil and water. As with phosphorus, excessive amounts of nitrogen in aquatic systems can result in overproduction — in cultural eutrophication. And the polluting of aquatic systems with overloads of nitrogen is increasing. Heavy losses of nitrate fertilizers from agricultural systems often result from runoff, especially in humid climates. Animal manure is potentially a primary source of nitrate pollution, especially near feedlots (fig. 50); fortunately, most feedlots are located in regions with low rainfall. One of the greatest sources of nitrate pollution is human effluent discharged directly from waste treatment facilities to waterways.

Figure 53— *We disrupt the sulfur cycle by injecting great quantities of sulfur dioxide (SO_2) into the atmosphere (box). Sulfur dioxide combines with moisture in the atmosphere to form sulfuric acid—a compound that can be harmful to animals and plants.*


SO
Combustion
SO_2
Rain
Uptake by plants
Decomposition
Gas
SO_2
O
SO_2
S
S
H_2S
H_2S
P
O
Iron Sulfides
Uptake by plants
Excretion
Fertilization
P

Sulfur dioxide. —We also are affecting the sulfur cycle by introducing great quantities of sulfur dioxide (SO_2) into the atmosphere (fig. 53). Sulfur dioxide usually is only a transitory step in the cycle, occurring in very low concentrations. Additions through combustion and refining of sulfur-bearing fossil fuels and smelting account for only about 20 percent of the total global amount (80 percent is from natural sources); however, concentrations of SO_2 in urban areas are causing serious problems.

Once it is in the atmosphere, SO_2 reacts with moisture to form sulfuric acid. When inhaled as a fine mist, or when attached to small particles, sulfuric acid can injure sensitive lung tissue; it is a major cause of bronchial asthma during air inversions. Low concentrations of SO_2 can injure and even kill many important crop plants, especially when it occurs with low concentrations of ozone.

Sulfur in the atmosphere produces *acid precipitation* in many areas. Downwind from industrial centers, the acidity of rainfall has increased up to 200 times in recent years. Sulfuric acid in the atmosphere damages paint, stone buildings, sculpture, and ancient artifacts. And the acidity of streams, sometimes great distances from the industrial sources, has also increased, harming fish and other aquatic life. Although the long-term effects of acid precipitation on terrestrial ecosystems are not well understood, this phenomenon emphasizes strongly that our activities in one location can adversely affect life processes many miles—even continents—away.

Heavy metals. —The cycles of many elements that are not essential for growth also have been adversely affected by people. The heavy metals—lead, mercury, and cadmium—that have always been present in low levels have been injected into the biosphere in large quantities by the burning of leaded gasoline, by smelting and other industrial processes, and by the use of pesticides. These elements magnify in food chains and accumulate in the blood and tissues of Consumers (including humans) at higher trophic levels, where they can cause severe neurological symptoms, chromosome breakage, and death.

Hydrocarbons (chlorinated). —The book *Silent Spring* by Rachel Carson alerted the public to the dangers of chlorinated hydrocarbon pesticides. The global spread of DDT and its unsuspected and dramatic impacts on nontarget organisms in distant areas point out the dangers of injecting huge quantities of synthetic materials into the biosphere (fig. 54).

The very characteristics of toxicity, persistence, and stability that made DDT attractive as an insecticide account for its spread and adverse effects. Insoluble in water but highly soluble in fats and oils, DDT accumulates in fatty tissues of organisms. It does not break down easily, and it continues to magnify in food chains. Indeed, a study along the northeastern Atlantic coast revealed the level of DDT in gulls to be a million times more concentrated than it was in the water!

Figure 54. —*Synthetic compounds, like the chlorinated hydrocarbon pesticides, become incorporated into biological cycles. When they magnify in food chains, they can be lethal to nontarget organisms great distances away.*

Death or impaired reproduction can result when organisms acquire high concentrations of DDT. Small fish can be killed from large doses of DDT that are stored in their yolk sacs; DDT in birds alters their calcium metabolism, resulting in death directly or indirectly when calcium-deficient egg shells break during incubation.

The greatest danger from DDT and similar compounds may not be from direct exposure but from subtle changes in the structure and function of the Game of the Environment. When beneficial nontarget organisms are killed by pesticides, food chains become shortened—simplified—and the Game is weakened. Materials that are substituted for chlorinated hydrocarbons are usually short-lived—they do not magnify in food chains. But the extreme toxicity of some of these substitutes poses real dangers through mishandling by humans.

Other synthetic compounds have attracted attention in recent years. Polychlorinated biphenyls (PCB's) used widely in industry are perhaps more dangerous than DDT. PCB's also persist and magnify in food chains and kill many predaceous organisms.

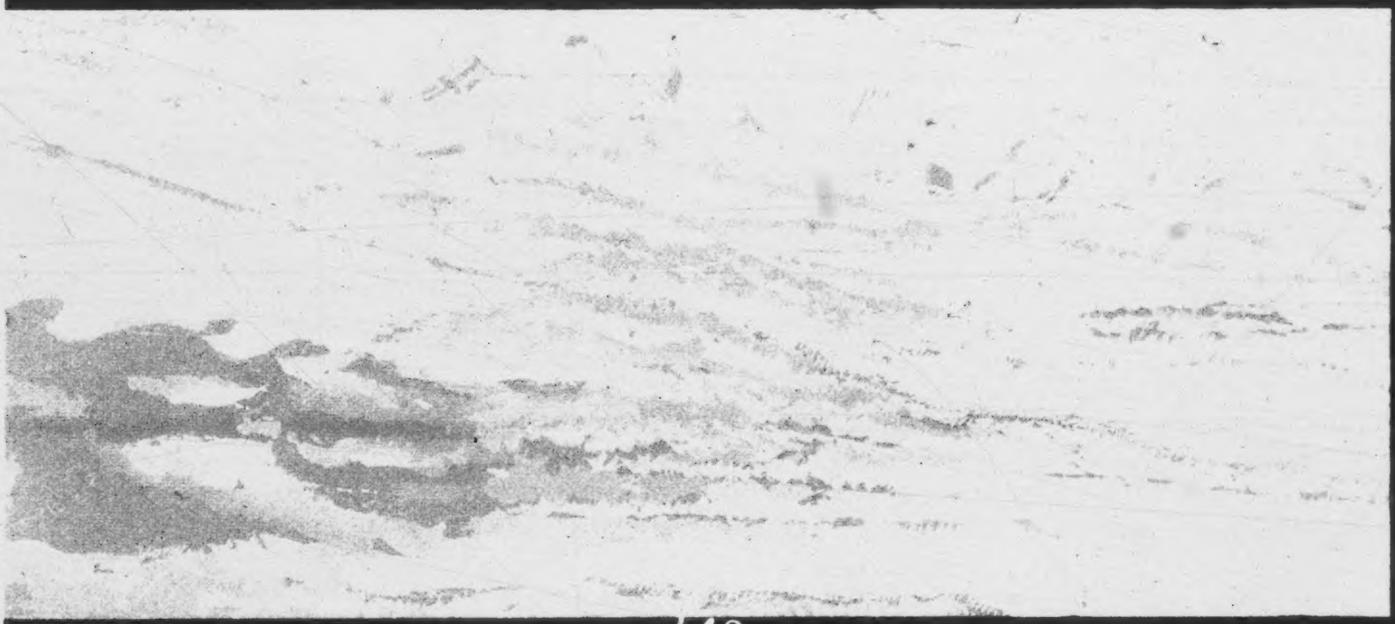
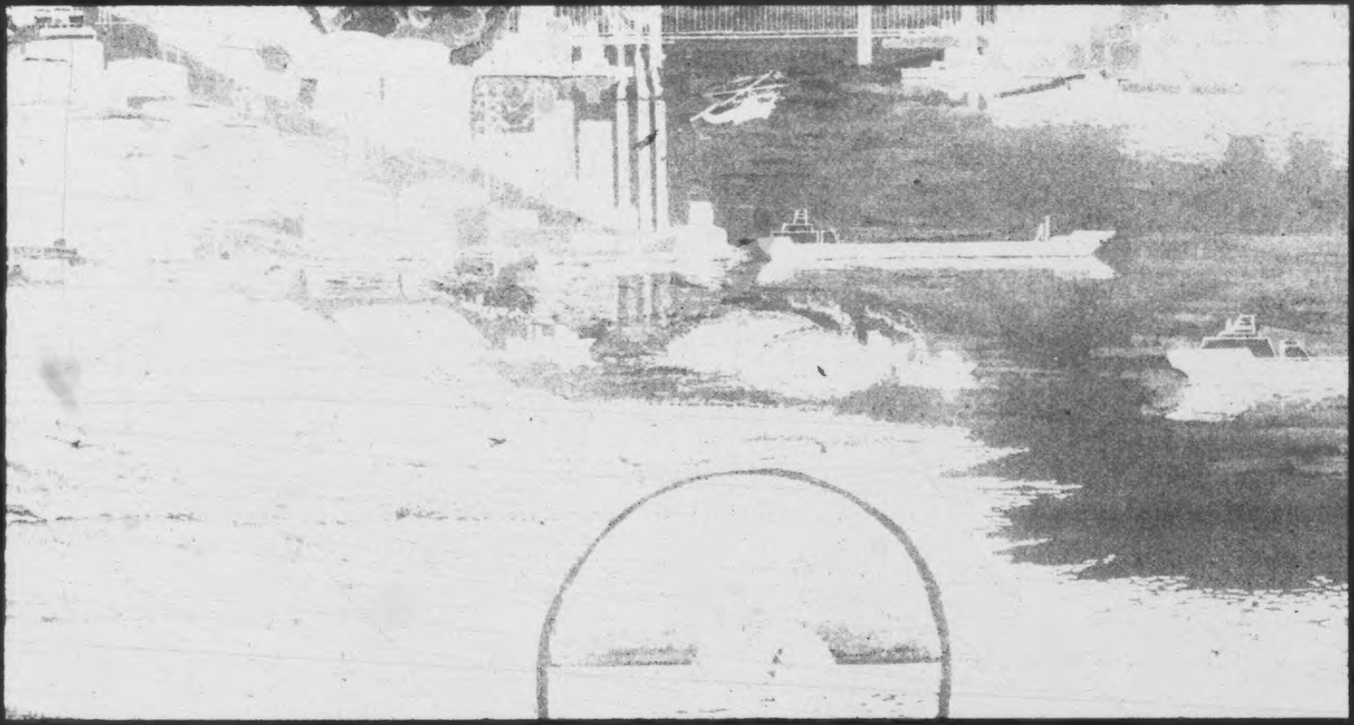


Figure 55. — *Oil spills are dramatic examples of pollution, but most oil pollution is not nearly as visible.*



Hydrocarbons (oil).—Oil pollution can be a dramatic event (fig. 55). Headlines tell of jumbo tankers breaking up, of offshore well blowouts, and of the potential failure of newly constructed pipelines. Such events reflect our increasing appetite for oil. As dwindling supplies necessitate exploiting reserves in increasingly inhospitable Arenas, the likelihood of serious accidents increases. But most oil pollution (80 to 90 percent) occurs during everyday shipping, refining, processing, and burning of hydrocarbons. The most important form of oil pollution is fallout of airborne hydrocarbons.

When hydrocarbons reach the oceans, they are diluted and dispersed. Eventually, they disappear through microbial degradation, evaporation, oxidation, and deposition. Along the way, however, great damage may occur to ocean life. Sometimes this damage is obvious, sometimes it is subtle and indirect. Thus, hydrocarbons can destroy vital parts of some food chains directly (for example, aquatic insects), can accumulate and magnify in food chains (for example, in large fish and birds near tops of food chains), and can interfere with the communication systems of organisms (for example, disruption of chemical "messages" from rivers to fish returning to spawn).

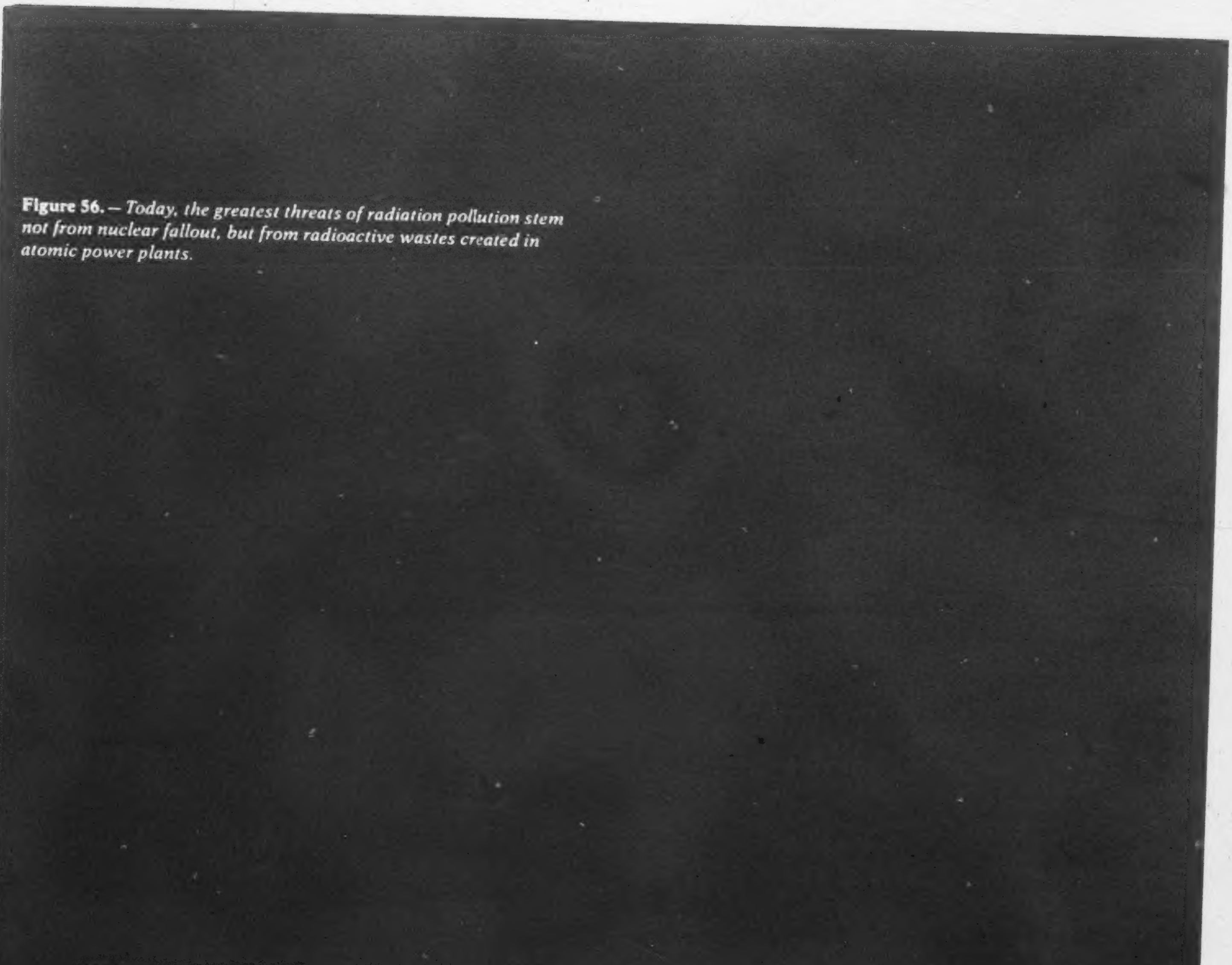


Figure 56.—*Today, the greatest threats of radiation pollution stem not from nuclear fallout, but from radioactive wastes created in atomic power plants.*

Radioactive materials.—Atomic bombs and the testing of nuclear weapons ushered forth the atomic age and the threat of radiation pollution (fig. 56). This threat is very great. The terrible radioactive fallout from massive atomic explosions is well known. But the dangers from radioisotopes that may enter biological cycles are also potentially great.

Radiostrontium, the product of uranium fission, is a good example of a material that can cause a cycle to subtly run amuck. Strontium "mimics" calcium and it can eventually become incorporated with calcium in human bones. Here, it is in close contact with blood-forming marrow—tissue that is especially sensitive to radiation damage.

Genetic damage to reproductive cells, with the threat of passing on mutations to unborn generations, can also occur from radiation. "Safe" levels are difficult to establish; the harmful effects of chronic exposure to low levels of radiation are still being studied.

There is little doubt that the greatest threat of pollution originates in transporting, storing, and reprocessing spent radioactive wastes. Large quantities of these wastes are now being stockpiled for reprocessing. They are a major liability; this material must be maintained—with no mistakes—for thousands of years. Wastes of other kinds, although posing less imminent threats, nevertheless affect our well-being as they interfere with biogeochemical cycling.

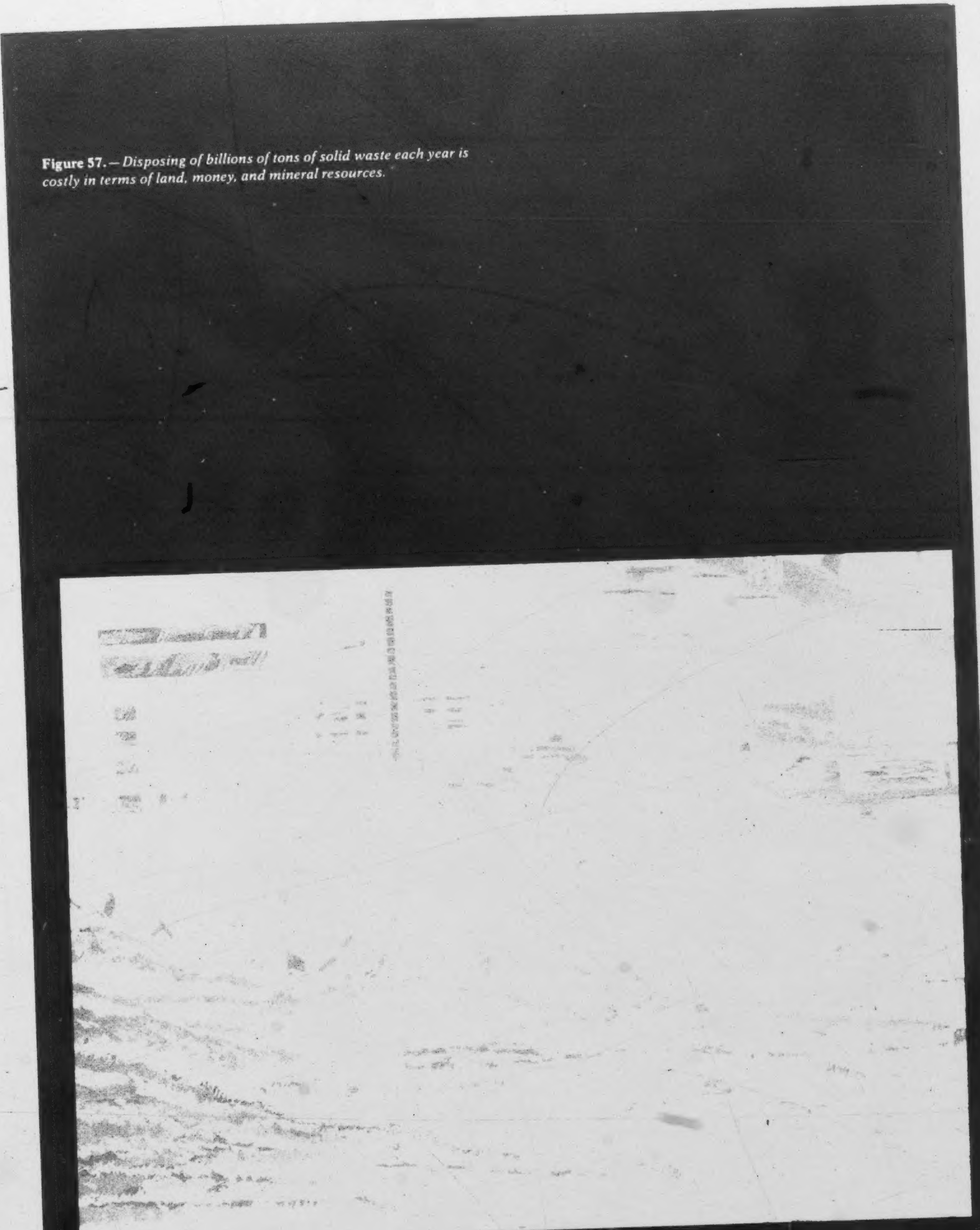


Figure 57.—*Disposing of billions of tons of solid waste each year is costly in terms of land, money, and mineral resources.*

Solid Waste. —Solid waste is increasing, especially in urban areas (fig. 57). Billions of tons are produced each year, and billions of dollars are spent in collecting and disposing of it. And disposing of solid waste is becoming more and more difficult. Poorly designed landfills can pollute land, water, and air, and the incineration of this material can contribute significantly to air pollution. Space is often unavailable for landfills near urban areas where huge quantities of trash must be disposed of each day. But the most serious and important aspects of disposal by burning or burial are the drain on our mineral resources and the loss of "waste" land such as wetlands and marshes.

Sewage. —The treatment of wastes by most of our sewage treatment plants involves only the primary or secondary phases or both. In primary systems, solids are screened and sedimented from waste water and then burned or buried. Secondary treatment consists of biological degradation of organic matter. The cheapest secondary system is a shallow oxidation pond where algae provide the aeration; mechanical aeration can speed up this process.

However, secondary treatment does not remove nutrients from sewage. When nutrients, such as phosphorus and nitrogen, discussed previously under "Some cycles run amuck," are transported back to natural Arenas, there must be sufficient space and food chains to handle them or pollution will result.

The expensive *tertiary* or advanced treatment includes the removal of phosphates, nitrates, organics, and other substances. More and more interest is being expressed in using terrestrial ecosystems as tertiary treatment systems.

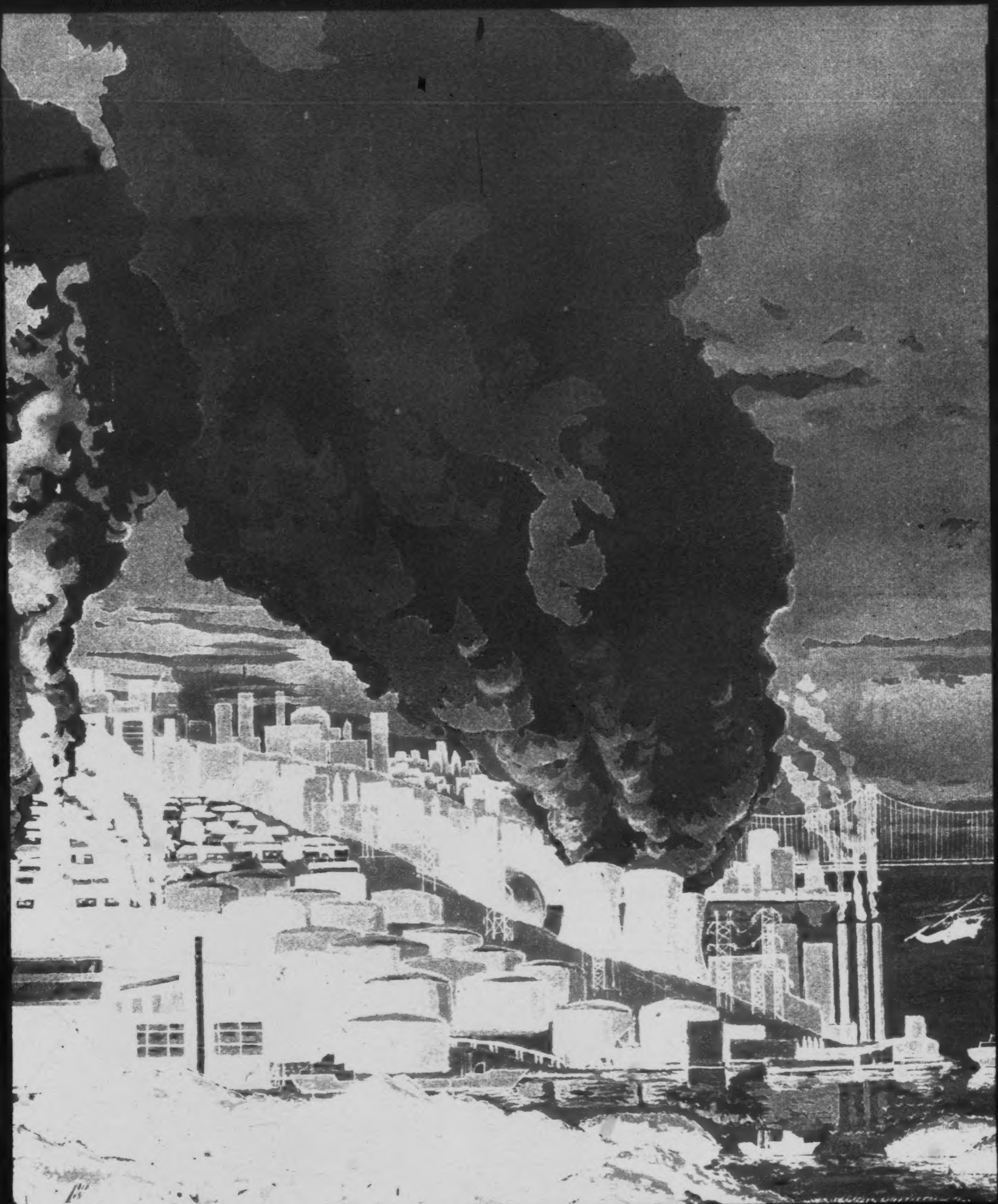


Figure 58. — *When too much heat, liberated into air or water, causes adverse effects, it is a pollutant.*

Messing up the flow of energy

Heat. — In figure 58, the cooling towers of an atomic power plant dominate the scene. This is appropriate because one of the greatest pollutants created by human activities is heat.

We learned earlier that energy flows only in one direction through ecosystems; each time it is transformed from one form to another, or passes from one organism to another, a portion of the energy is converted to heat and is dispersed into space. The biosphere must tolerate this heat. Too much heat produced in a local Arena becomes a *thermal* pollutant.

Over cities, thermal inversions occur when heat radiates upward on clear nights and the ground layer cools. Over valley cities, or when high-pressure air masses stagnate over the city, the cool air layer is trapped by the warm air above. Gaseous pollutants (nitrogen oxides, sulfur dioxide, smog) collect in the cool air. Thus, thermal air pollution can augment the adverse effects of other air contaminants.

The most serious thermal pollution stems from the use of water to cool industrial installations, especially fossil fuel and nuclear generating plants. Water taken from lakes, rivers, or estuaries to cool reactors is sprayed into the air in cooling towers or is returned to the water body. If this water is too hot, it becomes a pollutant. Tremendous quantities of water are now used to cool power plants, and it has been estimated that at least 25 percent of all fresh water flow in the United States will be used for this purpose by the year 2000.

Too much heat in aquatic Arenas can be harmful to the living Players. They can be:

☐ Killed directly by a sudden change in temperature.
☐ Rendered susceptible to parasites and diseases.
☐ Starved for oxygen.
☐ Starved for food because lower levels of their food chains were destroyed.
☐ Disrupted in their patterns of migration.

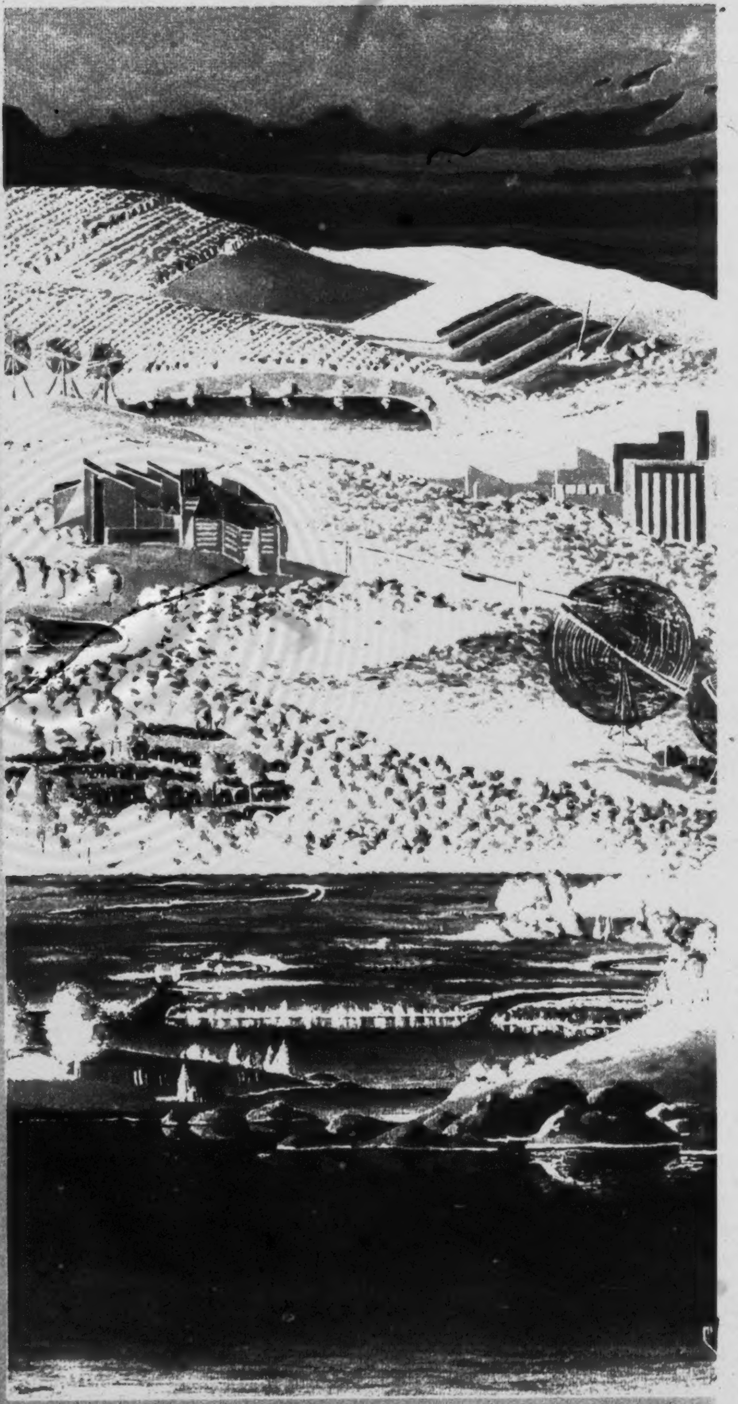
Overall, aquatic ecosystems can be degraded as eutrophication is speeded up, and as species composition changes to fewer and less desirable species.

The picture on pages 144 and 145 shows an ideal system where we, as the central Players of the Game of the Environment, have attuned ourselves and our actions to accommodate the Rules. Only a few of the myriad ways to *improve the Game* are shown — but all of these methods are available *now* or are easily within technological reach, and many of them are economically feasible (perhaps even profitable).

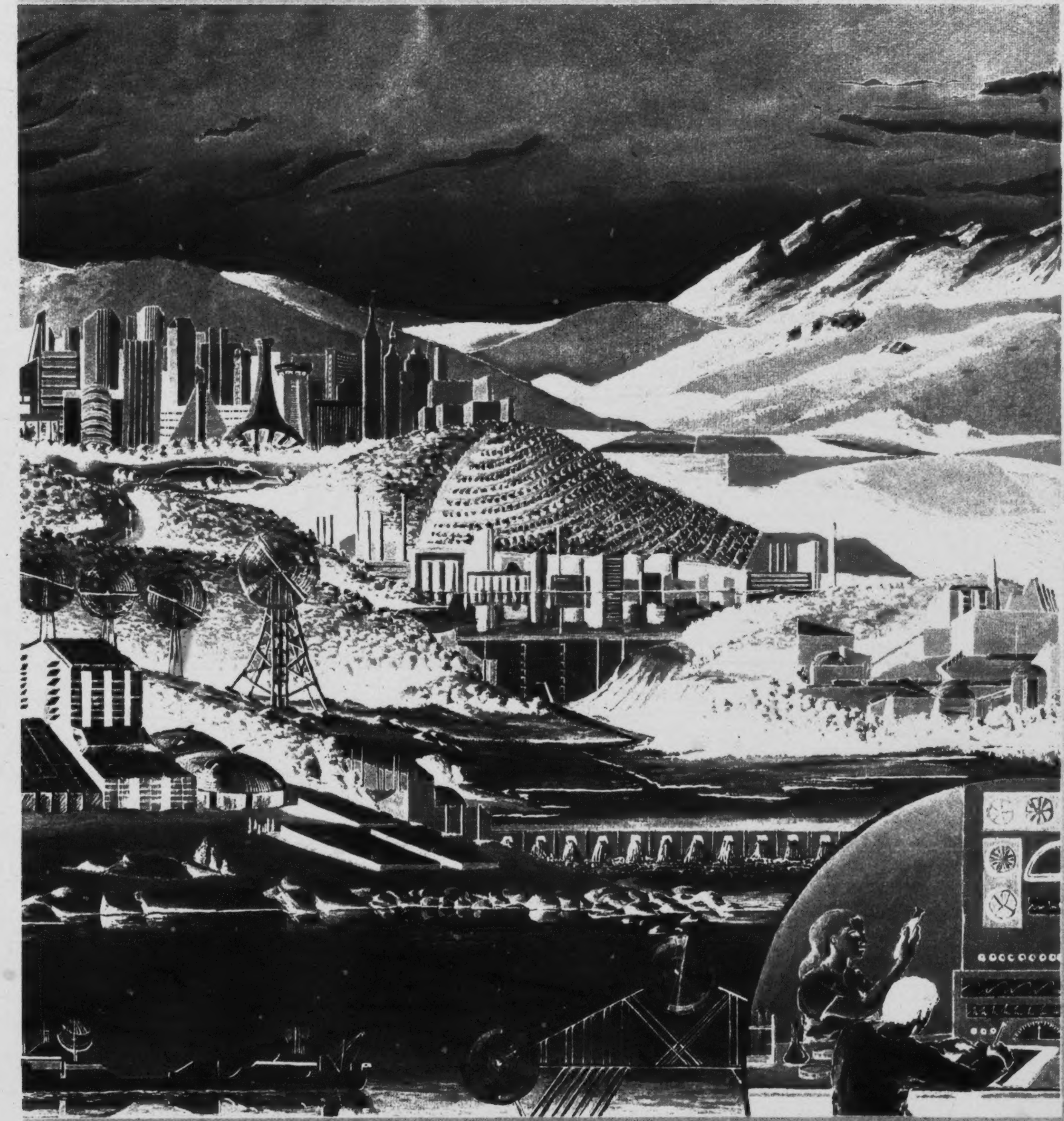
This illustration provides a sharp contrast to those that precede it. It presents the view that cities *will* remain the focal points of human culture, and that we *will* continue to dominate and exploit our environment. But it also points out the hope that this exploitation *will take place within the Rules* that govern our environment.

IN YOUR FUTURE ENVIRONMENTAL ARENA

Compare the illustration on page 144 with illustrations on pages 106, 114, and 122; list the similarities and differences between this illustration and each of the others.

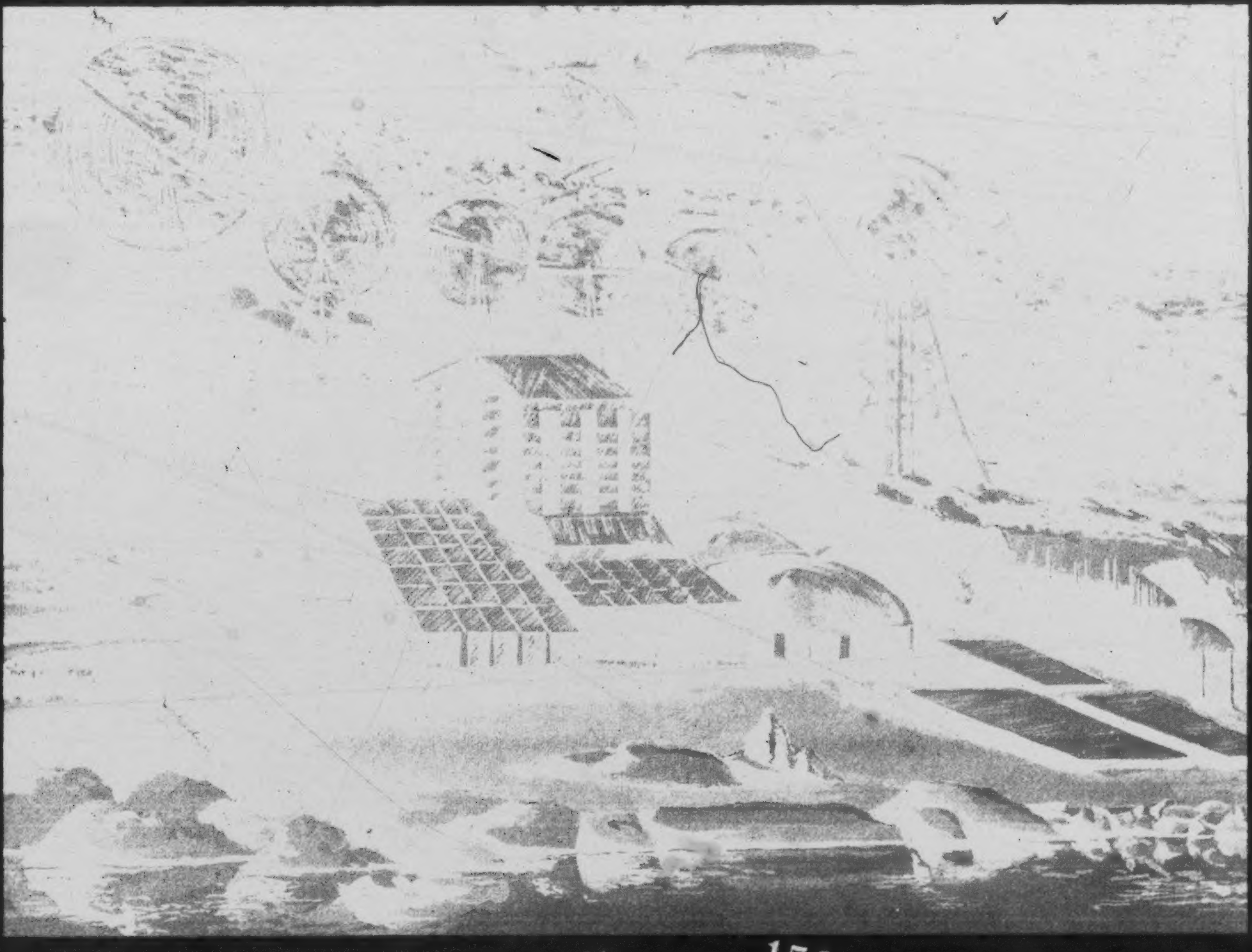


The Landscape of the Future



VI. IMPROVING THE GAME

Figure 59.—*Solar power and wind are two of the most promising sources of clean energy. We are just beginning to develop the techniques necessary to generate electricity with large windmills* (center background) *and to heat and cool buildings with solar energy* (solar collector panels on and near buildings). *The employment of solar power for many other uses is being explored in research programs around the world.*



156

ABIDING BY THE RULES

Energy

The *conservation* of energy offers the greatest opportunity for playing the Game of the Environment well. But, to be effective, conservation must involve each of us as individuals. It will be necessary for every person to make a strong personal commitment to conservation—a commitment that may require rethinking and perhaps reshaping of our personal lifestyles. Where appropriate, emphasis must be on the development of mass transit and the production of small cars; on the insulation of existing buildings and the construction of new ones in ways that conserve energy; and on the reorientation of agricultural and industrial processes that use less energy.

Along with these energy conservation practices we must embark on programs to develop alternate sources of clean energy. Recent reports indicate that both wind and solar power (fig. 59) can produce much more of our energy needs than had previously been suggested. While it is questionable whether nuclear fusion will ever be a usable source of energy, only massive research will disclose its feasibility.

Figure 60. — *While only conceptionalized in this illustration, strip mine reclamation* (background hills) *will be an integral step in the coal producing process. As our technologies improve, we may be able to actually make the sites more productive than they were originally.*

Our need for energy can only increase, even if we eliminate all wasteful practices. And our need may outstrip any progress we may make in developing alternative sources. Since strip mining for coal *will* continue to increase, we must ensure through reclamation practices (fig. 60) that the productivity of land is restored to as high a level as possible. And since we *will* continue to drill for oil and build pipelines in increasingly fragile Arenas, it is important that we learn from the hard environmental lessons of the past how to conduct these activities.

The absence of visible stack emissions in the picture illustrating the landscape of the future on page 144 indicates that the cities of the future that survive will be those that have "cleaned up." Emissions from industrial and power generating plants that burn fossil fuels will be reduced sharply as better ways to remove particulates and noxious materials are developed and as clean sources of energy, such as solar, wind, tidal, and hydroelectric power, become relatively more abundant. In certain circumstances, heated water from nuclear plants could be beneficial to ecosystems. With wise planning, "thermal enrichment" could be used to cultivate aquatic food species, to lengthen the existing seasons for fishing and recreation, and to heat buildings, including greenhouses and domestic water supplies. But these potential benefits must be weighed against the potential hazards of locating nuclear plants near population centers. In our future Arena, the quality of life will be an important component in the energy equation

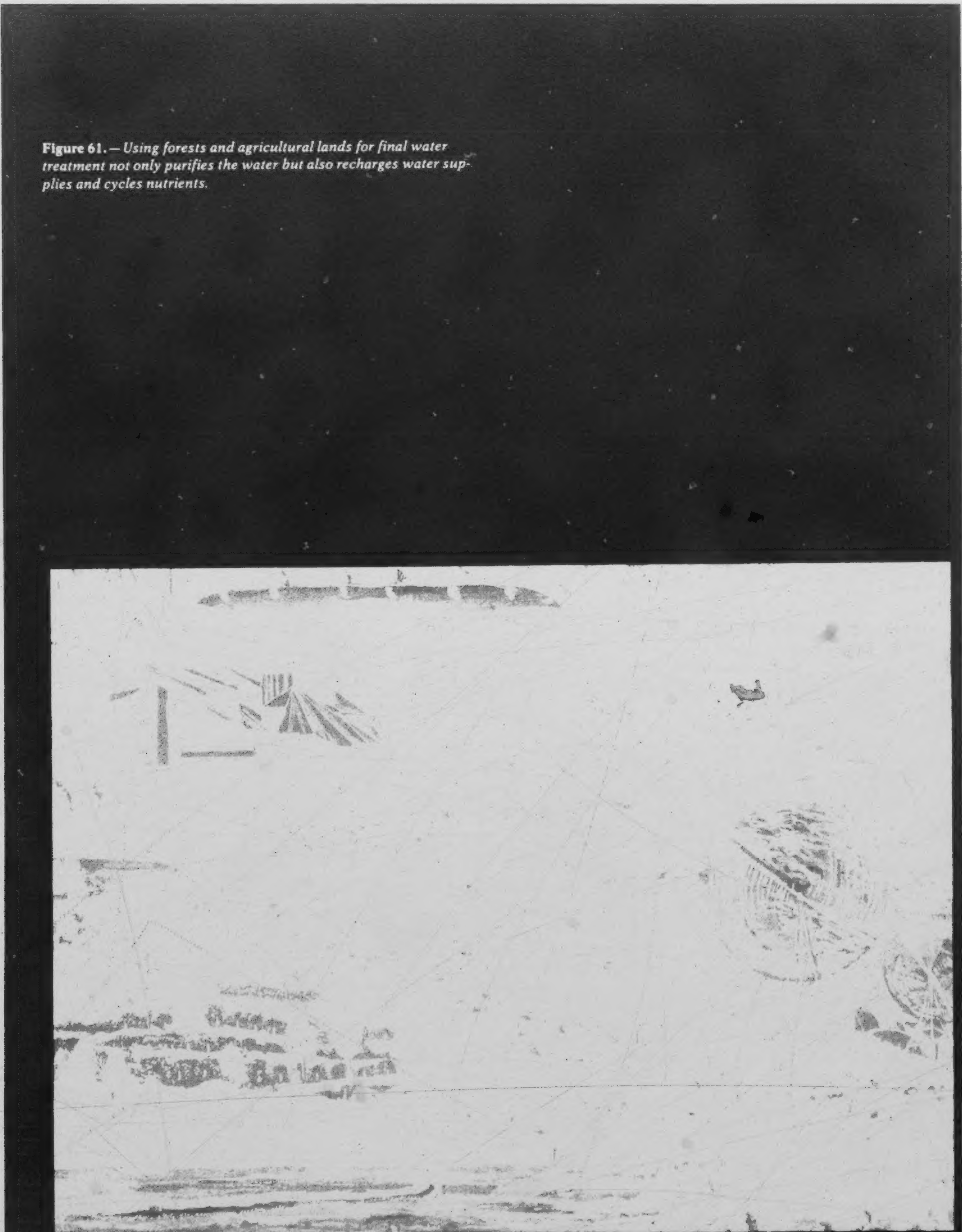


Figure 61. — *Using forests and agricultural lands for final water treatment not only purifies the water but also recharges water supplies and cycles nutrients.*

Material Cycling

Solid waste disposal systems—landfills, dumps, incinerators—also are conspicuously absent in the picture on page 144 . In our city of the future (indeed, in some European cities today) waste disposal will at last be coupled with reclamation. Nature's Rule that all essential materials must cycle within the system will become a way of life, for no other reason than necessity. There is simply no recourse but to change to a system where the circular movement of materials essential for our needs will be patterned after that of nature.

In our city of the future, it is likely that domestic and industrial solid waste will be collected and transported to reclamation centers and separated into combustibles and into metals and glass for recycling. The combustibles may be burned to power the system—or perhaps they may be degraded to produce *methane* (also used for power) and *compost* for city gardens and parks. It is quite possible that the value of recovered materials will offset the costs of collection and processing.

Sewage disposal systems will probably be linked directly to natural ecosystems at least for tertiary phases of water treatment. Studies have demonstrated the feasibility of using forests and agricultural lands as recycling systems, where nutrients are incorporated by the Producer Players before they can intrude into waterways (fig. 61), and where water can be returned to recharge city aquifers. In the future, the forest disposal systems will be cropped periodically to remove "excess" nutrients and prevent the overloading of cycles.

The primary concern in recycling materials in the future is the enormous energy that will be required to drive these cycles. The closing of the last mines of precious metals and industrial minerals will signal the end of our free ride. Just as great expenditures of energy were required by nature to separate, concentrate, and store mineral reserves eons ago, so, too, will we require great amounts of energy to repeatedly complete each phase of the cycle. But when all costs (including those of energy and environment) are considered, recycling still uses less energy than is used exploiting virgin materials; recycling also causes less air and water pollution and generates less solid waste. Recycling is one of the basic ecological Rules of the Game by which we must abide.

An abundant supply of energy will be critical if we are to prevent cycles from running amuck. And this presents a paradox because anticipated great increases in the use of coal and shale oil, the most likely stopgap energy sources, will result in great intrusions and disruptions of the sulfur, nitrogen, and carbon cycles—cycles that already are overloaded.

CAREFUL MANIPULATION OF ECOSYSTEMS

The picture illustrating the manipulation of ecosystems on page 106 shows many of our actions at their worst. From the time we have had the ways and means to do so, we have ruined many of our ecosystems. Ancient, advanced civilizations are no more; cities, cultural centers for centuries, lie forgotten in ruins; and once fertile lands are now deserts—primarily because we mistreated our agricultural Arenas.

Yet it must be reemphasized that these ecological disasters are not inevitable. There are many fine examples, especially in Europe, where land farmed for thousands of years is still highly fertile and productive; where exceedingly beautiful landscapes have been preserved because of the interactions of people and nature over centuries. What we have often thought of as "natural" and pleasing is often the result of playing within the Rules of the Game of the Environment (fig. 62).

Figure 62.—*Diversity of land-use patterns and preservation of prime agricultural lands—practices in accord with the Rules of the Game.*

This does not mean that we should not manipulate our environment — that we should stand aside and allow ecological succession to proceed unhindered. But it does suggest that we should heed the lesson that successional processes demonstrate, namely, that nature abhors a *biotic* vacuum. Following disturbance, the natural tendency is to reestablish a viable, solar subsidized, self-perpetuating ecosystem. Among other things, this lesson demonstrates two points: (1) Succession usually results in ecological diversity and (2) energy is required to hold successional processes in check.

In keeping with the first point, and as we discussed earlier, a diverse crop system is usually a hedge against devastation by pests or climate, and a landscape with diverse vegetational and land-use patterns can be esthetically desirable. The second point suggests that we must realize and accept the fact that great energy subsidies will be required to grow low-diversity crops to hold back succession. (In nature, succession is held in check by energy subsidies such as fire, insect defoliation, wind, and flood.) As supplies of fossil fuel wane, it will be imperative that top priority be given to using them for subsidizing ecosystems that produce food.

Figure 63. — *In the future, productive natural ecosystems such as this salt marsh and estuary will be protected as national assets.*

Of necessity, land-use policies must soon become alined with ecological principles. It no longer will be possible for urban sprawl to gobble up more than a million acres of prime agricultural land each year as it does now. Several European countries have led the way in preserving their agricultural land base; a number of our own States are considering legislation which would empower them to purchase agricultural land outright or to purchase the developmental rights. It is hoped that enlightened societies will enact these necessary policies long before the energy crunch does it for them.

In our future Arena, the sea itself will no longer be regarded as our infinite dumping ground. The global nature of the sea (as with the air of the biosphere) will demand international approaches to the monitoring and control of pollution, and to the exploration and the exploitation of the sea's minerals, energy reserves, and fisheries.

Productive natural ecosystems will be highly prized for their contributions to our well-being, and they will be protected against destruction. The salt marsh and estuary "nurseries" of our natural fisheries will be recognized and treated as national assets (fig. 63). Many states have enacted legislation to protect their coastal wetlands from large-scale, destructive activities.

Earthmanship will succeed only when the entire biosphere is treated as a single unit, when all actions, no matter how small, are in accord with the Rules of the Game. As the dominant Players of the Game of the Environment, our ultimate challenge will be to change from a pioneer Grand Exploiter to an enlightened and benevolent Steward of our environment. We have always had the capacity to do so. We now have the necessary motivation to do so—survival.

IN YOUR ENVIRONMENTAL ARENA

☐ List the ways in which your community could improve its Gamesmanship in living within the Rules.

☐ How would your lifestyle have to change?

☐ What actions would be required to improve the Game? By whom?

☐ In what ways would it be more costly to live in your improved community? In what ways would it be less costly?

The Forest Service has developed a package of materials to help you better understand environmental relationships. The package, *Investigating Your Environment,* contains lesson plans and an approach for studying water, soil, animals, forest, and people-produced communities. You may obtain a copy by writing to: U.S. Department of Agriculture, Forest Service, Office of Information, Environmental Education, Room 3235, P.O. Box 2417, Washington, D.C. 20013.

166

GLOSSARY OF ENVIRONMENTAL TERMS

A.

ABIOTIC: Nonliving.

ABSORPTION: The process of taking inorganic salts, in solution, into root hairs from soil water by osmosis. In pollution control, absorption is the dissolving of a soluble gas, present in an emission, in a liquid, from which it can be extracted.

ABYSSAL ZONE: The area of the bottom waters of the ocean depths.

ACCLIMATION: The physiological and behavioral adjustments of an organism to changes in its immediate environment.

ACID PRECIPITATION: Snow or rain with a pH value of less than 5.6.

ACTINOMYCETES: Small filamentous forms of bacteria that have some of the morphological characteristics of fungi. These organisms are important decomposers.

ADAPTION: A change in the structure or habit of an organism that enables it to better adjust to the environment.

ADVANCED WASTE TREATMENT: Waste water treatment beyond the secondary or biological stage that includes removal of nutrients such as phosphorus and nitrogen, and a high percentage of suspended solids. Advanced waste treatment, known as tertiary treatment, is the "polishing" stage of waste water treatment; it produces a high-quality effluent.

AEROBIC: Refers to life or processes that can occur only in the presence of oxygen.

AEROSOL: A suspension of liquid or solid particles in the air.

AGRICULTURAL POLLUTION: The liquid and solid wastes from all types of farming, including runoff from animal waste disposal areas and the land used for livestock and crop production; erosion and dust from plowing; animal manure and carcasses; and crop residues and debris.

AIR MONITORING: See monitoring.

AIR POLLUTION: The presence of contaminants in the air in concentrations that prevent the normal dispersion of substances by the air, and that interfere directly or indirectly with our health, safety, or comfort.

AIR POLLUTION EPISODE: Abnormally high concentrations of air pollutants, usually due to low winds and temperature inversion, and accompanied by an increase in illness and death. See inversion.

AIR QUALITY CRITERIA: The levels of pollution and lengths of exposure at which adverse effects on health and welfare occur.

AIR QUALITY STANDARDS: As prescribed by law, the level of pollutants in the outside air that cannot be exceeded during a specified time in a specified geographical area.

ALGA (Algae): Simple, one- to many-celled plants capable of carrying on photosynthesis.

AMBIENT AIR: Any unconfined portion of the atmosphere; the outside air.

ANAEROBIC: Refers to life or processes that occur in the absence of oxygen.

AQUACULTURE: The growing ("farming") of plants or animals in or under the seas, lakes, ponds, rivers, or other water bodies.

AQUATIC PLANTS: Plants that grow in water; includes those that float on the surface, grow up from the bottom of the body of water, or grow under the surface of the water.

AQUIFER: An underground bed or stratum of earth, gravel, or porous stone that contains water.

ASSIMILATION: Conversion or incorporation of absorbed nutrients into protoplasm. Also refers to the ability of a body of water to purify itself of organic pollution.

ATMOSPHERE: The gaseous envelope of air that surrounds the earth and is held to it by the force of gravity.

ATTRITION: Wearing or grinding down by friction. One of the three basic processes that contribute to air pollution; the others are vaporization and combustion.

AUTOTROPHIC ORGANISMS (Autotrophs): Self-nourishing: denotes those organisms capable of constructing organic matter from inorganic substances. See Producers.

B.

BACTERIA: Single-celled microorganisms that lack chlorophyll. Some bacteria are capable of causing human, animal, or plant diseases; others are essential because they break down organic matter in the air and in the water. With fungi, they comprise the decomposer level of food chains.

BATHYAL ZONE: The open water zone in an ocean below the level where light penetrates.

BENTHIC REGION: The bottom of a body of water. This region supports the benthos, a type of life that not only lives upon but also contributes to the character of the bottom.

BENTHOS: The plant and animal life whose habitat is the bottom of a sea, lake, or river.

BIOCHEMICAL OXYGEN DEMAND (BOD): A measure of the amount of oxygen consumed in the biological processes that break down organic matter in water. Large amounts of organic waste use up large amounts of dissolved oxygen; thus the greater the degree of pollution, the greater the BOD.

BIODEGRADABLE: The process of decomposing as a result of the action of microorganisms.

BIOGEOCHEMICAL CYCLES: The mechanisms by which essential and nonessential materials move through the biosphere to be used over and over again.

BIOLOGICAL CONTROL: A method of controlling pests by introduced or naturally occurring predatory organisms, sterilization, or the use of inhibiting hormones rather than by mechanical or chemical means.

BIOLOGICAL MAGNIFICATION: Buildup in the concentration of substances in successively higher levels of the food chain.

BIOLOGICAL OXIDATION: The process by which bacteria and other microorganisms feed on complex organic materials and decompose them. Self-purification of waterways and activated sludge and trickling-filter waste water treatment processes depend on this principle. This process is also called biochemical oxidation.

BIOMASS: The total weight (mass) of all living matter in a particular habitat or area.

BIOME: The complex of communities maintained by the climate of the region and characterized by a distinctive type of vegetation. The biomes of North America include the tundra, the desert, the eastern deciduous forest, the prairie, the northern boreal forest, and the western coniferous forests.

BIOSPHERE: The portion of the earth and its atmosphere capable of supporting life.

BIOTA: All species of plants and animals that occur within a certain area.

BIOTIC: Living.

BLOOM: A proliferation of living algae or other aquatic plants on the surface of lakes or ponds. Blooms are frequently stimulated by phosphate enrichment.

BOD: See biochemical oxygen demand.

BOG: A wetland that is formed in a former glacial lake by the accumulation of organic matter. Peat often accumulates to a depth of 40 feet.

BREEDER: A nuclear reactor that produces, from nonfissionable uranium-238, at least as much fissionable material (such as plutonium-239 or thorium) as is needed for the chain reaction, and usually more.

C.

CALORIE (GRAM CALORIE): The amount of energy required to raise the temperature of 1 gram (g) of water 1°C.

CARBON DIOXIDE (CO_2): A colorless, odorless, nonpoisonous gas that is a normal part of the ambient air. CO_2 is a product of fossil fuel combustion; some researchers have theorized that an excess of CO_2 raises atmospheric temperatures.

CARBON MONOXIDE (CO): A colorless, odorless, highly toxic gas that is a normal byproduct of incomplete fossil fuel combustion. CO, one of the major air pollutants, can be harmful in small quantities if breathed over a certain period of time.

CARNIVORES: Organisms that eat animals.

CARRYING CAPACITY: The maximum number of living things that can be supported indefinitely by a given ecosystem.

CELLULOSE: A chemical substance that forms the walls of plant cells; the woody part of trees and plants. Its formula is $(C_6H_{10}O_5)n$.

CHILLING EFFECT: The lowering of the earth's temperature due to the increase of atmospheric particulates that inhibit penetration of the sun's energy.

CLIMATE: The kind of weather a place has over a period of years, based on conditions of heat and cold, moisture and dryness, clearness and cloudiness, wind and calm.

CHLORINATED HYDROCARBONS: A class of generally long-lasting, broad-spectrum insecticides of which the best known is DDT, first used for insect control during World War II. Similar compounds include aldrin, dieldrin, heptachlor, chlordane, lindane, endrin, mirex, benzene hexachloride (BHC), and toxaphene. The qualities of persistence and effectiveness against a variety of insect pests were long regarded as highly desirable in agriculture, public health, and home uses. But research has revealed that these same qualities may represent a potential hazard by accumulating in the food chain and persisting in the environment.

CHRONIC: Marked by long duration or frequent recurrence, as a disease.

CLEARCUTTING: Removing an entire stand of timber from a forest area.

CLIMAX COMMUNITY: A relatively stable community that appears to perpetuate itself in the absence of disturbance.

COASTAL ZONE: Coastal waters and adjacent lands that exert a measurable influence on the uses of the sea and its ecology.

COLIFORM INDEX: An index of the purity of water based on a count of its coliform bacteria.

COLIFORM ORGANISM: Any of a number of organisms common to the intestinal tract of humans and animals, and whose presence in waste water is an indicator of pollution and of potentially dangerous contamination.

COMBUSTION: Burning. Technically, a rapid oxidation accompanied by the release of energy in the form of heat and light. It is one of the three basic factors that contribute to air pollution; the others are attrition and vaporization.

COMMUNITY: The group of populations occupying a particular habitat or area.

COMPOST: Relatively stable decomposed organic material.

COMPOSTING: A controlled process of degrading organic matter by microorganisms. (1) Mechanical: a method in which the compost is continually and mechanically mixed and aerated. (2) Ventilated cell: compost is mixed and aerated by being dropped through a vertical series of ventilated cells. (3) Windrow: an open-air method in which compostable material is placed in windrows, piles, or ventilated bins or pits and is occasionally turned or mixed. The process may be aerobic or anaerobic.

CONDENSATION: The process whereby water is changed from a gas (water vapor) to a liquid.

CONSUMERS: Organisms that live off others. Usually they are classified as primary consumers (herbivores), secondary consumers (carnivores), and microconsumers (decomposers).

COOLING TOWER: A device that removes excess heat from water used in industrial operations, usually in electric power generation.

CULTURAL EUTROPHICATION: Acceleration by human action of the natural aging process of bodies of water.

CYCLING: See Biogeochemical Cycling.

D.

DDT: The first of the modern chlorinated hydrocarbon insecticides whose chemical name is 1, 1, 1-trichloro-2, 2-bis (p-chloriphenyl)-ethane. It has a half-life of 15 years, and its residues can become concentrated in the fatty tissues of certain organisms, especially fish. Because of its persistence in the environment and its ability to accumulate and magnify in the food chain, EPA banned the registration and interstate sale of DDT for nearly all uses in the United States, effective December 31, 1972.

DECOMPOSERS: Bacteria and fungi that chemically degrade (rot or decay) organic matter.

DECOMPOSITION: Reduction of the net energy level and change in chemical composition of organic matter due to the actions of aerobic or anaerobic microorganisms.

DEFOLIATION: Removal of leaves from plants.

DESALINIZATION: Removal of salt from seawater or brackish water.

DETERGENT: Synthetic washing agent that, like soap, lowers the surface tension of water, emulsifies oils, and holds dirt in suspension. Environmentalists have criticized the use of detergents because most have large amounts of phosphorus-containing compounds that contribute to the eutrophication of waterways.

DETRITUS: The particulate organic matter included in the decomposition of dead material.

DETRITUS FOOD CHAIN: The transfer of energy from one food (trophic) level to another by decomposers.

DIATOMS: Any of numerous microscopic, unicellular aquatic algae that have hard shells composed mostly of silica.

DIGESTION: The biochemical decomposition of organic matter. The digestion of sewage sludge takes place in tanks where the sludge decomposes; this results in partial gasification, liquefaction, and mineralization of pollutants.

DILUTION RATIO: The ratio of the volume of water of a stream to the volume of incoming waste. The capacity of a stream to assimilate waste is partially dependent upon the dilution ratio.

DISINFECTION: Effective killing by chemical or physical processes of all organisms capable of causing infectious disease. Chlorination is the disinfection method commonly used in sewage treatment.

DISSOLVED OXYGEN (DO): The oxygen dissolved in water or sewage. Adequately dissolved oxygen is necessary for the survival of fish and other aquatic organisms and for the prevention of offensive odors. Low concentrations of dissolved oxygen generally are caused by the discharge of excess organic solids that have high BOD—the result of inadequate waste treatment.

DIVERSITY OF ORGANISMS: Biological complexity (the number of species) of an ecosystem. In many instances, the ecosystem becomes more stable as diversity increases.

DREDGING: A method for deepening streams, swamps, or coastal waters by scraping and removing solids from the bottom. The resulting mud is usually deposited in marshes in a process called filling. Dredging and filling can disturb natural ecological cycles. For example, dredging can destroy oyster beds and other aquatic life; filling can destroy the feeding and breeding grounds for many fish species.

DUMP: A land site where solid waste is disposed of in a manner that usually does not protect the environment.

DUST: Fine-grain particulate matter that is capable of being suspended in the air.

DYSTROPHIC LAKES: Lakes between eutrophic and swamp stages of aging. Such lakes are shallow and have high humus content, high organic matter content, low nutrient availability, and high BOD.

E.

ECOLOGICAL IMPACT: The total effect of an environmental change, either natural or human-caused, on the ecology of the area.

ECOLOGICAL SUCCESSION: The changes, over time, in the structure and function of an ecosystem. Primary succession occurs on sites where no previous vegetation existed (bare sand); secondary succession occurs on sites that supported vegetation previously (abandoned fields).

ECOLOGY: The interrelationships of living things to one another and to their environment, or the study of these interrelationships.

ECOSYSTEM: The interacting system of a biological community and its nonliving environment; also, the place where these interactions occur.

EFFLUENT: A discharge of pollutants into the environment, partially or completely treated or in their natural state; usually refers to discharges into water.

EMISSION: Usually refers to discharges in air. See effluent.

EMISSION STANDARD: The maximum legal amount of a pollutant that can be discharged from a single mobile or stationary source.

ENERGY: The capacity to do work.

ENERGY FLOW: The one-way passage (transfer) of energy through an ecosystem.

ENERGY PYRAMID: Passage of energy from one trophic level to another. Because much energy is lost as heat (80 to 90 percent) in each transfer, the shape of the energy pyramid is always "right side up."

ENRICHMENT: The addition of nitrogen, phosphorus, and carbon compounds or other nutrients into a lake or other waterway that greatly increases the growth potential for algae and other aquatic plants. Most frequently, enrichment results from the inflow of sewage effluent or from runoff from farmlands.

ENVIRONMENT: The sum of all external conditions and influences that affect the development and, ultimately, the survival of an organism.

EPILIMNION: The warm, less dense top layer in a stratified lake.

EROSION: The wearing away of the land surface by wind or water. Erosion occurs naturally from weather or runoff, but it is often intensified by our land-clearing practices.

ESTUARY: An area where freshwater meets saltwater; for example, a bay, mouth of a river, salt marsh, or lagoon. Estuaries are delicate ecosystems; they serve as nursery, spawning, and feeding grounds for a large group of marine life, and they provide shelter and food for birds and wildlife.

EUTROPHICATION: The normally slow aging process by which a lake evolves into a bog or marsh and ultimately assumes a completely terrestrial state and disappears. During eutrophication, the lake becomes so rich in nutritive compounds—especially phosphorus—that algae and other microscopic plant life bebecome superabundant, thereby "choking" the lake and causing it to dry up. Eutrophication may be accelerated by many human activities.

EUTROPHIC LAKE: A shallow lake that is choked by weeds at the edge and very rich in nutrients. The water is characterized by large amounts of algae, low water transparency, low dissolved oxygen, and high BOD.

EUTROPHIC ZONE: The surface layer of water bodies where light penetrates; the zone where photosynthesis occurs.

EVAPORATION: The process whereby water is changed from a liquid to a gaseous state (water vapor).

F.

FALLOUT: The radioactive particles or dust that fall to the earth after an atomic explosion. Fallout may be assumed always to be dangerously radioactive.

FEEDLOT: A confined space where large numbers of livestock are fattened for slaughter. Although an economical method of fattening beef, a feedlot concentrates a large amount of animal wastes in a small area. Excrement cannot be handled by the soil on a feedlot as it can on an open range where cattle are scattered. Runoff from feedlots also contributes excessive quantities of nitrogen, phosphorus, and potassium to nearby waterways, thus contributing to eutrophication.

FILLING: The process of depositing dirt and mud in marshy areas, often to create more land for real estate development. Filling can disturb natural ecological cycles. See Dredging.

FILTRATION: In waste water treatment, the mechanical process that removes particulate matter by separating water from solid material, usually by passing it through sand.

FINITE RESOURCES (Nonrenewable): Resources such as minerals and fossil fuels that exist as fixed, depletable supplies.

FIRST LAW OF THERMODYNAMICS: The law that states that while energy can be transformed from one type to another, it can neither be created nor destroyed.

FISSION: The process by which neutrons and energy are released when the nucleus of a heavy element (uranium-235, plutonium-239) splits into nuclei (usually two) of lighter elements.

FIXATION: The process of making stable by decreasing or destroying volatility, fluidity, etc.

FLOOD PLAIN: A lowland fringing a watercourse. It serves a valuable function by containing large volumes of water in times of flood. Development on flood plains, therefore, is considered unwise.

FOOD CHAIN: The transfer of food energy from organisms in one trophic level to those in another. There are two pathways or "circuits": the grazing food chain and the detritus food chain.

FOOD WEB: The complex and interlocking series of food chains.

FOREST: A large area of land covered with trees.

FOSSIL FUELS: Coal, oil, and natural gas; called fossil fuels because they are derived from the remains of ancient plant and animal life.

FUNGI: Small, often microscopic plants without chlorophyll. Some fungi infect and cause disease in plants or animals; other fungi are useful in stabilizing sewage or in breaking down wastes for compost.

FUNGICIDE: A pesticide chemical that kills fungi or prevents them from causing diseases, usually on plants of economic importance. See Pesticide.

FUSION: The process by which energy is released when nuclei of light elements combine to form the nucleus of a heavier element.

G.

GAME FISH: Those species of fish sought by sports fishermen; for example, salmon, trout, black bass, and striped bass. Game fish are usually more sensitive to environmental changes and the degradation of water quality than "rough fish."

GASEOUS CYCLE: Biogeochemical cycles in which the primary reservoir is the atmosphere.

GASIFICATION: The processing of coal to produce synthetic natural gas (SNG).

GENERATOR: A device that converts mechanical energy into electrical energy.

GEOTHERMAL ENERGY: Energy derived from the heat of the earth's interior.

GRAZING FOOD CHAIN: Transfer of food energy from plants to animals, excluding the actions of decomposers.

GREEN BELT: An area where building is restricted; it often serves as a buffer between sources of pollution and concentrations of population.

GREENHOUSE EFFECT: The heating effect of the atmosphere upon the earth. Light waves from the sun pass through the air and are absorbed by the earth. The earth then reradiated this energy as heat waves that are absorbed by the air, specifically by carbon dioxide. The air thus behaves like glass in a greenhouse, allowing the passage of light but not heat. Many scientists believe that an increase in the atmospheric concentration of CO_2 can eventually cause an increase in the earth's surface temperature.

GROUNDWATER: The supply of freshwater under the earth's surface in an aquifer or soil that forms the natural reservoir for use by humans.

GROUNDWATER RUNOFF: Groundwater that is discharged into a stream channel as spring or seepage water.

H.

HABITAT: The sum of environmental conditions of a specific place that is occupied by an organism, a population, or a community.
HALF-LIFE: The time it takes certain materials such as persistent pesticides or radioactive isotopes to lose half their strength. For example, the half-life of DDT is 15 years; the half-life of radium is 1,580 years.
HAZARDOUS AIR POLLUTANT: According to law, a pollutant to which no ambient air quality standard is applicable, and that may cause or contribute to an increase in death or in serious illness. Asbestos, beryllium, and mercury have been declared hazardous air pollutants.
HEAT ISLAND EFFECT: An adverse atmospheric condition that is peculiar to cities. Tall buildings, heat from pavements, and concentrations of pollutants create a "dome" of haze that prevents rising hot air from being cooled at its normal rate. A self-contained circulation system is put into motion that can be broken by relatively strong winds. If such winds are absent, the heat island can trap high concentrations of pollutants and cause a serious health hazard.
HEAVY METALS: Metallic elements with high molecular weights; in low concentrations, generally toxic to plant and animal life. Such metals are often residual in the environment, and they are biologically accumulative. Examples include mercury, chromium, cadmium, arsenic, and lead.
HERBICIDE: A pesticide chemical used to destroy or control the growth of weeds, brush, and other undesirable plants. See Pesticide.
HERBIVORE: An organism that feeds on vegetation.
HETEROTROPHIC ORGANISM (Heterotrophs): Organism that depends on organic matter for food. Includes all animals and some plants.
HUMUS: Decomposed material that is a highly complex mixture of organic and inorganic substances.
HYDROCARBONS: A vast family of compounds containing carbon and hydrogen, found especially in fossil fuels. Some hydrocarbons are major air pollutants, some may be carcinogenic, others contribute to photochemical smog.
HYDROELECTRIC POWER: Electricity generated by turbines that operate by water flow.
HYDROGEN SULFIDE (H_2S): A gas, made up of hydrogen and sulfur, that has an odor characteristic of rotten eggs. It is emitted in the natural decomposition of organic matter, and it is the natural accompaniment of advanced stages of eutrophication. H_2S is also a byproduct of refining activity and the combustion of oil during power plant operations. In heavy concentrations, it can cause illness.
HYDROSPHERE: The water portion of the earth, including water vapor.
HYPOLIMNION: The lower depths of a lake below the thermocline.

I.

INCINERATION: A controlled process by which solid, liquid, or gaseous combustible wastes are burned and changed into gases; the residue contains little or no combustible material.
INFILTRATION: The flow of a fluid into a substance through pores or small openings; commonly used in hydrology to denote the flow of water into soil material.
INFRARED: The part of the invisible spectrum whose wavelengths are longer than those of the red part of the visible spectrum. Most of the heat from sunlight is from infrared rays.
INGESTION: The act of taking food and water, etc., into the body for digestion.
INTEGRATED PEST CONTROL: A system of managing pests by biological, cultural, and chemical means.
INTERTIDAL ZONE: The zone along the shore between high and low tides (littoral zone).
INVERSION: An atmospheric condition where a layer of cool air is trapped by an upper layer of warm air. Inversions spread polluted air horizontally rather than vertically so that contaminating substances cannot be widely dispersed. An inversion of several days can cause an air pollution "episode."
ISOTOPE: A variation of an element having the same atomic number as the element itself, but having a different atomic weight because of a different number of neutrons. Different isotopes of the same element have different radioactive behavior.

K.-L.

KILOCALORIE: Unit of energy equal to 1,000 calories.
LAGOON: In waste water treatment, a shallow pond, usually not natural, where sunlight, bacterial action, and oxygen interact to restore waste water to a reasonable state of purity.
LAKE: A large body of water entirely or nearly surrounded by land. Lakes differ from ponds chiefly in size, but this carries with it profound changes in all the principal factors of environment—light, temperature, and dissolved gases—with their effects upon nutrition.
LANDFILL: A place where solid waste is dumped. See Sanitary Landfilling.
LEACHING: The process by which soluble materials in soil such as nutrients, pesticide chemicals, and contaminants are washed into a lower layer of soil, or are dissolved and carried away by water.
LEAD: A heavy metal that may be hazardous to health if breathed or ingested.
LIFE CYCLE: The phases, changes, or stages through which an organism passes during its lifetime.
LIGNIN: The organic substance that holds together the individual fibers of wood.

LIMITING FACTOR: Factors such as temperature, light, water, and nutrients that limit the ability of an organism to grow and survive.

LIMNITIC ZONE: In lakes, the open-water region that supports plankton and fish as the principal Producers and Consumers.

LIMNOLOGY: The study of the physical, chemical, meteorological, and biological aspects of fresh water.

LITTORAL ZONE: The area on or near the shore of a water body. In the ocean, this area is called the intertidal zone.

M.

MACROCONSUMERS: Organisms, chiefly animals, which ingest other organisms or particulate organic matter.

MACRONUTRIENTS: Chemicals required by organisms in relatively large quantities. Carbon, oxygen, hydrogen, and nitrogen are examples.

MARSH: A low-lying tract of soft wetland that provides an important ecosystem for a variety of plant and animal life, but that often is destroyed by dredging and filling. Trees and shrubs are absent.

MEGALOPOLIS: A large continuous urban belt formed by a number of cities that adjoin each other.

MERCURY: A heavy metal, highly toxic if breathed or ingested. Mercury is residual in the environment, and it accumulates in aquatic organisms, especially fish and shellfish. Chronic exposure to airborne mercury can seriously affect the central nervous system.

METHANE: Colorless, nonpoisonous, and flammable gaseous hydrocarbon. Methane (CH_4) is emitted by marshes and by dumps undergoing anaerobic decomposition.

MICROCONSUMERS: See Decomposers.

MICRONUTRIENTS: Chemicals required by organisms in small quantities. Included in this group are copper, nickel, and magnesium.

MICROORGANISM (Microbes): Microscopic organisms including bacteria, yeasts, fungi, some algae, and protozoans.

MONITORING: Periodic or continual determination of the amount of pollutants or radioactive contamination in the environment.

MONOCULTURE: The growing of a single species to the exclusion of others on a large area of land.

MULCH: A layer of wood chips, dry leaves, straw, hay, plastic strips, or other material placed on the soil around plants to retain moisture, to prevent weeds from growing, and to enrich soil.

MUTATION: The process of change in the genetic material that determines the characteristics of a species. When caused by chemicals, mutations are usually deleterious.

N.

NATURAL GAS: A fuel gas that occurs naturally in certain geologic formations. Natural gas is usually a combustible mixture of methane and hydrocarbons.

NATURAL SELECTION: The process by which the organisms best adapted to their environment survive and those less well adapted are eliminated.

NICHE: The ecological role played by organisms. Also refers to specific places where individual organisms can live (spatial niche).

NITRIC OXIDE (NO): A gas formed in great part from atmospheric nitrogen and oxygen when combustion takes place under high temperature and high pressure, as in internal combustion engines. NO itself is not a pollutant; however, in the ambient air, it converts to nitrogen dioxide, a major contributor to photochemical smog.

NITROGEN DIOXIDE (NO_2): A compound produced by the oxidation of nitric oxide in the atmosphere; a major contributor to photochemical smog.

NITROGEN FIXATION: The process by which some bacteria and algae convert atmospheric nitrogen into nitrates.

NITROGENOUS WASTE: Waste of animal or plant origin that contains a significant concentration of nitrogen.

NO: A notation meaning oxides of nitrogen. See Nitric Oxide.

NONRENEWABLE RESOURCES: See Finite Resources.

NUCLEAR POWER PLANT: Any device, machine, or assembly that converts nuclear energy into some form of useful power, such as mechanical or electrical power. In a nuclear electric power plant, heat produced by a reactor is generally used to make steam to drive a turbine that, in turn, drives an electric generator.

NUCLIDE: An atomic species in which all atoms have the same atomic number and mass number; an individual atom in such a species.

NUTRIENTS: Elements or compounds essential as raw materials (building blocks) for the growth and development of an organism; for example, carbon, oxygen, nitrogen, and phosphorus. See Macronutrient and Micronutrient.

O.

OIL SHALE: Fine-grain shale rock impregnated with natural hydrocarbons.

OIL SPILL: The discharge of oil into oceans, bays, or inland waterways. Methods of controlling oil spills include chemical dispersion, combustion, mechanical containment, and absorption.

OLIGOTROPHIC LAKE: A deep lake that has a low supply of nutrients and thus contains little organic matter. Such lakes are characterized by high water transparency and high dissolved oxygen.

OMNIVORES: Organisms that eat animals and plants.

ORGANIC: Referring to or derived from living organisms. In chemistry, any compound containing carbon.

ORGANISM: Any living human, plant, or animal.

ORGANOPHOSPHATES: A group of pesticide chemicals, containing phosphorus, that are used to control insects. These compounds are short-lived and, therefore, do not usually contaminate the environment. However, organophosphates such as parathion are extremely toxic when initially applied and exposure to them can interfere with the normal processes of the nervous system, causing convulsions and eventually death. Other organophosphates such as malathion are low in toxicity and relatively safe for humans and animals; malathion is a common ingredient in household insecticides.

OUTFALL: The mouth of a sewer, drain, or conduit where effluent is discharged into a body of water.

OXIDANT: Any oxygen-containing substance that reacts chemically in the air to produce new substances. Oxidants are primary components of photochemical smog.

OXIDATION: The combining of oxygen with another element to form one or more new substances. Burning is one kind of oxidation. Organic matter is oxidized by the action of aerobic bacteria.

OXIDATION POND: A constructed lake or pond in which organic wastes are reduced by bacterial action. Oxygen often is injected into the pond to speed the process.

OZONE (O_3): A pungent, colorless, toxic gas. Ozone is a component of photochemical smog and is considered a major air pollutant.

OZONE LAYER: A layer of ozone in the high atmosphere that protects life on earth by filtering out lethal ultraviolet radiation.

P.

PAN: Peroxyacetyl nitrate, a pollutant created by the action of sunlight on hydrocarbons and nitrogen oxides in the air. PAN's are an integral part of photochemical smog.

PARTICULATE: Finely divided solid or liquid particle in the air or in an emission. Particulates include dust, smoke, fumes, mist, spray, and fog.

PATHOGEN: Any organism that incites disease.

PATHOGENIC: Inciting or capable of inciting disease.

PCB's: Polychlorinated biphenyls, a group of organic compounds used in the manufacture of plastics. In the environment, PCB's have many of the same characteristics as DDT and, therefore, may be confused with that pesticide. PCB's are highly toxic to aquatic life, they persist in the environment for long periods of time, and they are biologically accumulative.

PERCOLATION: Downward flow or infiltration of water through the pores or spaces of rock or soil.

PEST: Harmful or noxious insects, microorganisms, weeds, or animals.

PESTICIDE: An agent used to control pests. This can be an insecticide for use against harmful insects; a herbicide for weed control; a fungicide for control of plant diseases; a rodenticide for killing rats and mice; a germicide used in disinfectants; an algaecide, or a slimicide. Some pesticides can contaminate water, air, or soil, and can accumulate in humans, animals, and the environment if misused. Some of these chemicals also interfere with the reproductive processes of predatory birds and possibly other animals.

pH: A measure of the acidity or alkalinity of a material, liquid, or solid. pH is represented on a scale of 0 to 14; 7 represents a neutral state; 0 represents the most acid, and 14, the most alkaline.

PHENOLS: A group of organic compounds that in very low concentrations produce a foul taste or odor in water. In higher concentrations, they are toxic to aquatic life. Phenols are byproducts of petroleum refining; tanning; and textile, dye, and resin manufacturing processes.

PHOSPHORUS: An element that, while essential to life, contributes to the eutrophication of lakes and other bodies of water.

PHOTOCHEMICAL OXIDANTS: Secondary pollutants formed by the action of sunlight on the oxides of nitrogen and hydrocarbons in the air; they are the primary contributors to photochemical smog.

PHOTOCHEMICAL SMOG: Air pollution associated with oxidants rather than with sulfur oxides or particulates; smog causes necrosis, chlorosis, and growth alteration in plants, and is an eye and respiratory irritant in humans.

PHOTOSYNTHESIS: The process by which chlorophyll-bearing (green) plants combine carbon dioxide and water in the presence of light energy to form sugars; it is the conversion of light energy to potential chemical energy of food. Oxygen is released in the process.

PHYSIOGRAPHY: Physical geography.

PHYTOPLANKTON: The plant portion of plankton.

PLANKTON: The often microscopic floating or weakly swimming plant and animal life in a body of water.

POLLUTANT: Any introduced gas, liquid, or solid that makes a resource unfit for a specific purpose.

POLLUTION: The presence of matter or energy whose nature, location, or quantity produces undesirable environmental effects.

POND: A body of still water smaller than a lake.

POTABLE WATER: Water suitable for drinking or cooking.

PRECIPITATION: Water from the atmosphere that falls to the ground as rain, snow, sleet, or hail.

PREDATOR: Organisms that live by preying on other organisms. Predators are at or near the tops of food chains.

PREY: Organisms that serve as food for predators.

PRIMARY TREATMENT: The first stage in waste water treatment in which nearly all floating or settleable solids are mechanically removed by screening and sedimentation.

PRODUCERS: Green plants that synthesize their own Organic Compounds from Inorganic Substances. See Autotrophs.

PROTOPLASM: The complex living matter of organisms.

R.

RADIATION: The emission of fast atomic particles or rays by the nucleus of an atom. Some elements are naturally radioactive; others become radioactive after bombardment with neutrons or other particles. The three major forms of radiation are alpha, beta, and gamma.
RADIOECOLOGY: The study of the effects of radiation on plants and animals in natural communities.
RADIOISOTOPE: Radioactive isotope whose nuclei emit radiation spontaneously. Radioisotopes such as cobalt-60 are used in the treatment of disease.
RADIONUCLIDE: A radioactive nuclide.
RECYCLING: The process by which waste materials are transformed into new products in such a way that the original products may lose their identity.
RED TIDE: Seawater colored red or orange by a proliferation or bloom of a certain type of plankton; this bloom often causes massive fish kills. Though natural phenomena, blooms are believed to be stimulated by phosphorus and other nutrients discharged into waterways by humans.
REFUSE RECLAMATION: The process of converting solid waste into commercial products. For example, the composting of organic solid waste yields a salable soil conditioner.
RESOURCE RECOVERY: The process of obtaining materials or energy, particularly from solid waste.
RESPIRATION: Aerobic oxidation of food or organic substances by organisms. Respiration releases usable energy, carbon dioxide, and water.
RIVER BASIN: The total area drained by a river and its tributaries.
RUNOFF: The portion of rainfall, melted snow, or irrigation water that flows across the ground (overland flow) and eventually is returned to streams. Runoff can pick up pollutants from the air or on the land and carry them to bodies of water.

S.

SALINITY: The degree of salt in water.
SANITARY LANDFILLING: A method of solid waste disposal on land that protects the environment; waste is spread in thin layers, compacted to the smallest practical volume, and covered with soil.
SAPROTROPHIC ORGANISMS (Saprotrophs): Organisms that obtain food by absorbing the products of decomposition; they live off dead organisms.
SCRUBBER: An air pollution control device that uses a liquid spray to remove pollutants from a gas stream, as for example in a smoke stack, by absorption or chemical reaction. Scrubbers also lower the temperature of the emission.
SECOND LAW OF THERMODYNAMICS: The law that states that energy is degraded to less useful forms (heat) as it flows through an ecosystem.
SECONDARY TREATMENT: Waste water treatment beyond the primary stage in which bacteria consume the organic parts of the wastes. This biochemical

action uses trickling filters or activated sludge. Effective secondary treatment removes virtually all floating and settleable solids, and about 90 percent of both BOD_5 and suspended solids. Disinfection by chlorination usually is the final stage of the secondary process.

SEDIMENT: Soil particles (sand, silt, clay, and minerals) washed from land into water systems as a consequence of natural or human activities.

SEDIMENTATION: In waste water treatment, the settling out of solids by gravity.

SEEPAGE: Water that flows through the soil.

SELECTIVE HERBICIDE: A pesticide for killing only certain types of plants, especially broad-leafed weeds, but not other plants such as farm crops or lawn grasses.

SILT: Very fine particles of earth, sand, clay, etc. Often silt is carried by moving water and deposited as a sediment.

SILTATION: The formation or deposition of silt.

SMELTING: The process of melting ore to extract metals or impure metal to refine it.

SNG: *See* Synthetic natural gas.

SOLAR RADIATION: The radiant energy of the sun.

SOLID WASTE: Useless, unwanted, or discarded material with insufficient liquid content to be free flowing. (1) *Agricultural:* solid waste from raising and slaughtering animals and processing animal products, and orchard and field crops. (2) *Commercial:* waste from stores, offices, and other activities that do not actually turn out a product. (3) *Industrial:* waste from industrial processes and manufacturing. (4) *Institutional:* waste from institutions such as educational, health care, and research facilities. (5) *Municipal:* residential and commercial solid waste generated within a community. (6) *Pesticide:* residue from the manufacturing, handling, and use of chemicals designed to kill plant and animal pests. (7) *Residential:* waste that usually originates in a residential environment; sometimes called domestic solid waste. See Waste.

SOLID WASTE DISPOSAL: The ultimate disposition of refuse that cannot be salvaged or recycled.

SPOIL: Dirt or rock that has been removed from its original location; specifically, materials that have been dredged from the bottom of waterways.

STABILITY: The ability of an ecosystem (the landscape, numbers of species, populations) to tolerate changes in the environment.

STABLE AIR: An air mass that remains in the same position rather than moving horizontally or vertically. Stable air does not disperse pollutants, and it can lead to high concentrations of air pollutants.

STAGNATION: Lack of wind in an air mass or lack of motion in water; both tend to trap and concentrate pollutants.

STRATIFICATION: Separation into layers.

STRIP MINING: The process by which rock and topsoil strata overlying ore or fuel deposits are scraped away by mechanical equipment; also known as surface mining.

SUCCESSION: See Ecological Succession.

SULFUR DIOXIDE (SO_2): A heavy, pungent, colorless gas formed primarily by the combustion of fossil fuels. SO_2 damages the respiratory tract as well as vegetation and materials; it is considered a major air pollutant.

SURVEILLANCE SYSTEM: A monitoring system to determine environmental quality. Surveillance systems can be established to monitor progress in meeting environmental standards, and to identify potential episodes of high pollutant concentrations in time to take preventive action.

SWAMP: A marsh that contains wetland trees and shrubs.

SYNERGISM: The cooperation of separate substances so that the total effect is greater than the sum of the effects of the substances acting independently.

SYNTHETIC NATURAL GAS: (SNG) A gas produced from coal by the process of gasification. While SNG eliminates the high sulfur oxide and particulate air pollution problems associated with coal, it is relatively inefficient because about 25 percent of the coal's energy is lost in the conversion process.

T.

TERRESTRIAL: Of the land, not the water.

TERTIARY TREATMENT: Waste water treatment beyond the secondary or biological stage; includes the removal of nutrients such as phosphorus and nitrogen, and a high percentage of suspended solids. Tertiary treatment, also known as advanced waste treatment, produces a high-quality effluent.

THERMAL INVERSION: See Inversion.

THERMAL POLLUTION: Degradation of water quality by the introduction of heated effluent; it is primarily the result of the discharge of cooling waters from industrial processes, particularly from electrical power generation. Even small deviations from normal water temperatures can affect aquatic life. Thermal pollution usually can be controlled by cooling towers.

THRESHOLD DOSE: The minimum dose of a substance that is necessary to produce a measurable physiological or psychological effect.

TOLERANCE: The relative capacity of an organism to endure an unfavorable environmental factor; the amount of a chemical on any food considered safe for consumption by humans or other animals.

TOXICANT: A substance that kills or injures an organism or that alters its environment through a chemical or physical action. Examples are cyanides, phenols, pesticides, and heavy metals. Toxicants are used especially for insect control.

TOXICITY: The quality of or degree to which a substance is poisonous or harmful to plant or animal life.

TRANSPIRATION: Evaporation of water from the leaves of plants.

TROPHIC LEVEL (Food level): The level at which food energy is transferred from one organism to another.

TROPOSPHERE: The layer of the atmosphere extending 7 to 10 miles above the earth. Vital to life on earth, the troposphere contains clouds and moisture that reach earth as rain or snow.

U.

UPWELLING REGION: The area adjacent to a continent where nutrient-rich bottom waters are brought to the surface where they can be used by organisms at the bottoms of food chains.

ULTRAVIOLET: The invisible part of range of the spectrum just beyond the violet. The visible spectrum from violet to red comprises only a small part of the whole range of wavelengths radiated by a source such as the sun. The spectrum goes on into the ultraviolet in one direction and into the infrared in the other.

V.

VAPOR: The gaseous phase of substances that usually are liquid or solid at atmospheric temperature and pressure; for example, steam and phenolic compounds.

VAPORIZATION: The change of a substance from the liquid to the gaseous state. One of three basic factors that contribute to air pollution; the others are attrition and combustion.

VOLCANISM: The phenomena associated with volcanoes and volcanic activity.

W.

WASTE: (1) *Bulky waste:* an item whose large size precludes or complicates handling by normal collecting, processing, or disposal methods. (2) *Construction and demolition waste:* building materials and rubble from construction, remodeling, repair, and demolition operations. (3) *Hazardous waste:* waste that requires special handling to avoid illness or injury to persons or damage to property. (4) *Special waste:* waste that requires extraordinary management. (5) *Wood pulp waste:* wood or paper fiber residue from manufacturing processes. (6) *Yard waste:* plant clippings, prunings, and other discarded material from yards and gardens; also known as yard rubbish. See solid waste.

WATER POLLUTION: The addition of sewage, industrial waste, or other harmful or objectionable material to water in sufficient quantities to measurably degrade water quality.

WATERSHED: The area drained by a stream.

WATER TABLE: The upper level of groundwater.

WETLAND: An area that is regularly wet or flooded, and where the water table stands at or above the land surface for at least part of the year.

Z.

ZOOPLANKTON: Planktonic animals that supply food for fish.

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